THE USE OF VIRTUAL REALITY IN THE ASSESSMENT OF COGNITIVE FUNCTIONING AFTER BRAIN INJURY

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DECLARATION

This thesis has been composed by myself and the work contained herein is my own.

Signed

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ABSTRACT

Brain injury causes a variety of cognitive impairments which vary according to the severity and mechanism of injury. Commonly reported impairments concern attention and memory functions. A thorough and accurate assessment of cognitive deficits is essential for the planning and implementation of rehabilitation. The most widely used measures of cognitive assessment tend to be paper and pencil type tests that are carried out in a clinical setting. These have been criticised however as lacking in ecological validity. In the past 15 to 20 years, assessments have been developed which aim to address this concern, namely; The Rivermead Behavioural Memory Test and The Test of Everyday Attention. Research is beginning to address the issue of the use of virtual reality (VR) in rehabilitation after brain injury but little consideration has been given to the use of VR in the assessment of cognitive functioning after brain injury. This may prove to be a superior form of assessment which relates more directly to individual functioning in real life situations. The present study therefore concerns the use of a virtual reality computer programme, as a means of assessing memory and attention functioning. 43 brain injured individuals were assessed using the VR assessment , standard clinical tests of memory and attention and the two newer assessments which are considered to be more ecologically valid. Relatives/carers completed checklists about the observed memory failures of the individuals taking part in the study, as a measure of everyday memory problems. A correlational design is used to analyse the relationships between the different assessments. Further analysis concerns the extent to which the VR assessment involves memory and attentional processing. The potential of the VR task as an ecologically valid assessment of cognitive functioning is discussed.

1 : INTRODUCTION

1.1 COGNITIVE DEFICITS AFTER NEUROLOGICAL INSULT

Many different types of cognitive deficit arise after brain insult. Disorders of language, reasoning, planning/organisation, memory and attention are all commonly found and may be permanent to some degree (Hebb, 1942; Lezak, 1995). Brain insult may affect several different systems, including attention, memory and executive or frontal lobe problems (Lezak, 1995). Auerbach writes that "disorders of memory and attention are widely viewed as the most common and persistent sequelae of non penetrating traumatic brain injury." (Auerbach, 1986, p.1) Memory and attention are also commonly reported as a result of penetrating brain injury. Several investigators have found memory deficits as a result of closed-head-injury, for example, on specific tasks such as List Learning (Brouwer, 1985; Levin and Eisenberg, 1979) and recognition memory (Brooks, 1974; Mack and Winegardner, 1984). Memory deficits have also been found on nonverbal tasks (Brooks, 1974; Mack and Winegardner, 1984).

Attention is indispensable for the optimal functioning of memory, for learning and for the performance of physical tasks (Njiokiktjien, 1988). Not surprisingly therefore, attentional defects may underlie many of the cognitive problems after neurological insult. Even mild or moderate brain injuries, for example, can produce a disorder of concentration or of speed of cognitive processing. Such deficits may affect the individual's ability to function for many months (van Zomeren and Deelman, 1978) or even years (van Zomeren, Brouwer and Deelman, 1984) after injury. Cognitive processing speed has been shown to be an important factor in accounting for memory deficits in elderly subjects, but its effect on memory has not yet been fully studied in patients with neurological damage.

Memory impairment is one of the most handicapping of cognitive deficits, often preventing return to work or independent living (British Psychological Society, 1989). However, most memory disordered patients do not exhibit pure amnesic syndromes but typically have other cognitive problems such as word finding difficulties, impaired judgment, reasoning and planning, and a general slowing of cognitive processing (Wilson, 1988). Within the field of neurological rehabilitation it is vital to delineate the precise basis of the presenting problem in order to devise and implement appropriate and effective interventions.

1.2 BRAIN RESERVE CAPACITY

An individual may sustain a relatively severe head injury, with resultant neurological damage, but without any obvious signs of change in cognitive functioning. Alternatively, a head injury may result in disproportionately severe symptoms in some cases. (This apparent discrepancy may lead to misattribution of symptoms and a failure to carry out rehabilitation appropriately.) Such seemingly contradictory outcomes make sense however when the concept of brain reserve capacity is considered.

Satz (1993) describes the concept of brain reserve capacity and symptom onset after neurological insult. The theory of brain reserve capacity postulates a threshold whereby a certain amount of brain tissue must be damaged before clinical symptoms become apparent. Threshold theory has been applied to cases of Parkinson's disease where 85% of the cells in the nigrostriatal system must be depleted, with a similar decrease in dopamine levels, before clinical symptoms of the disease become apparent (Satz, 1993). Similar examples are found for dementia and normal ageing. For example, neurofibrillary tangles are largely confined to the hippocampus and parahippocampal gyrus, in the subthreshold stage of Alzheimer's disease, that is, before it reaches clinical significance. (The neurofibrillary tangles present in non dementing elderly are also confined to these structures.) When the neurofibrillary tangles increase to affect more than 60% of brain tissue, including the hippocampus and cerebral cortex, clinical dementia is more likely to appear.

Quinn, Rossor and Marsden (1986) suggest that brain reserve capacity can be defined and measured in terms of specific functional anatomical relations. For example, the number of Lewy bodies in Parkinson's disease and the number of neurofibrillary tangles in Alzheimer's disease would serve as direct measures of brain reserve capacity. More easily accessible measures however, are thought to be general intelligence and educational level as they are likely to influence the brain reserve capacity on an individual basis. This relates to the concept of premorbid abilities whereby, if an individual has higher premorbid IQ and level of education, their brain reserve capacity will be correspondingly greater. This is by virtue of fact that higher educational level and overall cognitive abilities result in a more dense network of neurons within the brain. The higher the premorbid cognitive abilities therefore, the greater the brain reserve capacity and the higher the threshold for that individual. Satz (1993) points out however, that general intelligence and educational level are indirect measures of brain reserve capacity and are therefore imprecise.

How brain reserve capacity is actually measured is a practical issue that is not within the scope of the current study. What is important, is the actual theory and its relevance to all forms of neurological insult.

Satz (1993) discusses two main postulates in relation to a hypothetical situation whereby two individuals experience identical brain lesions, as follows;

Postulate A: Greater brain reserve capacity acts as a protective factor.
The individual with greater brain reserve capacity will not experience cognitive difficulties as the damage incurred would remain below the threshold for that individual.

Postulate B: Less brain reserve capacity acts as a vulnerability factor
The individual with less brain reserve capacity is more likely to experience cognitive impairment as the damage incurred goes beyond the threshold for that individual.

Both postulates therefore, rely on the assumption that individual differences exist in brain reserve capacity which ultimately determine the threshold level. The theory is supported through studies concerning autopsy, computed tomography, MRI and PET as well as evoked potential studies of the brain (Satz, 1993). Although this literature is extremely interesting and gives a greater overview of the brain reserve capacity and threshold concepts, the basic outline of these concepts, as presented so far, is sufficient for current purposes. The main premise is that if an individual suffers some form of neurological insult, he/she will experience cognitive difficulties if the brain damage incurred exceeds his/her threshold of brain reserve capacity.

1.3 FOCAL AND DIFFUSE NEUROLOGICAL DAMAGE

Another aspect of neurological damage that is important in determining cognitive impairment, is whether the damage is focal or diffuse. Simplistically, focal damage is likely to result in relatively specific cognitive difficulties (theory of localization) whereas more diffuse damage may affect several circuits within the brain, thus causing a more complex array of cognitive impairments. Subjects who took part in the current study had different histories of types of neurological insult. Some patients had relatively focal lesions (cerebrovascular accidents, for example) while others had more diffuse damage (traumatic brain injury as a result of a road traffic accident, for example).

The diversity of cognitive deficits after neurological insult is complicated further by the fact that systems within the brain do not function independently, but are interconnected in an extremely complex manner. It is quite conceivable therefore that a focal lesion could affect several systems within the brain if the part of the brain that is damaged has multiple connections with other systems. The correlation between extent of damage and resultant cognitive deficits is therefore not as simple as it may initially seem. As a general rule however, more diffuse damage is likely to result in more functional systems being affected.

In relation to brain reserve capacity, it can be understood that deficits may occur as a result of focal or diffuse lesions, in relation to the threshold for each individual system within the brain. The size, location and momentum of a lesion therefore, will determine which functional systems are likely to be damaged, while the threshold for each functional system will determine whether or not the individual will actually experience any cognitive difficulties.

1.4 WHAT IS MEANT BY COGNITIVE FUNCTION?.

1.4.1 The 'how' and the 'what'

In a seminal discussion of approaches to rehabilitation, von Steinbuchel and Poppel (1983) stress that it is important to clarify how different cognitive functions are mapped within the brain and how lesions result in functional deficits. The principle of localisation is widely accepted within the field of neuropsychology, although different neuropsychologists vary greatly in the *extent* to which they think this principle applies to human cognition. The concept of localisation of function is the basis of many neurological rehabilitation programmes. This does not imply however, that a specific brain area necessarily represents only one function. Strict localisationist ideas have been largely rejected. It is now more commonly accepted that brain systems overlap and interact. Von Steinbuchel and Poppel (1993) point out that different functions may coexist within the same area of the brain, that is, they overlap spatially. These functions however, are governed by different neurochemicals. Quite simply, the same localised brain area may host several cognitive functions, but different neurotransmitters are responsible for controlling the different functions. Von Steinbuchel and Poppel state that the "spatial segregation of cognitive functions has been repeatedly demonstrated, but not in a pure sense whereby distinct functions are governed entirely within a particular area" (von Steinbuchel and Poppel, 1993, p.1). Different subcomponents of cognitive functions may also be represented in different areas within the brain. The overall brain structure therefore, is extremely complex with a multitude of interconnections between neurons, linking different cognitive systens throughout different regions of the brain.

The current study is concerned with the assessment of two major cognitive functions; memory and attention. A major source of controversy within neuropsychology however, is the ambiguity about *what is meant by function.* Von Steinbuchel and Poppel differentiate between two classes of functions: "those that are responsible for the content of subjective experience (the 'what') and those that have to be considered as the formal or logistical prerequisite of mental activity (the 'how')" (von Steinbuchel and Poppel, 1993, p.1). The contrast here is between the functions that result in the actual cognitive experience and the more subordinate functions that enable mental activity to come about in the first place. These subordinate functions alone do not result in any subjective cognition, but they are *essential prerequisites* for subjective cognition.

The current investigator finds the term 'enabling functions' helpful in clarifying the meaning of the 'how'. Similarly, the term 'advanced functions' is found to be helpful in clarifying the meaning of the 'what'. In relation to the current study, this 'how/what' classification is extremely important. It is imperative to understand the basic aspects of cognitive functioning that actually *enable* the more advanced cognitive functions to occur. As mentioned previously, this study is concerned with two main cognitive functions; memory and attention. It is necessary in the first place therefore, to clarify exactly what functions occur to *enable* memory and attention processing. It is then necessary to address exactly what the memory and attention functions *are,* and how they interact within the overall picture of cognition.

The next three sections will attempt to clarify these distinctions:

1) The 'how' - the enabling functions (Section 1.4.2).
2) The 'what' - the advanced functions, specifically memory and attention (Section 1.4.3).
3) Interaction between memory and attention functions (Section 1.4.4).

1.4.2 The 'how' - or the 'enabling' functions

Von Steinbuchel and Poppel (1993) describe the enabling functions in terms of 'mental activity'. They propose that two mental activity variables directly affect the individual's ability to carry out specific, and more advanced, cognitive functions:

(1) activation

(2) temporal coordination.

A change in these mental activity variables as a result of neurological damage, may lead to severe cognitive deficits and/or functional impairments.

Activation level

The activation level within the brain has far reaching implications for cognitive functioning. For example, if there is insufficient activation, patients will be unconscious and unable to carry out any form of advanced cognitive processing. Similarly, after regaining consciousness, activation levels will still be extremely low with the result that cognitive processing will be much slower and far more difficult. Reduced activation can be reflected in a decrease in attention, and extreme tiredness. In some instances however, heightened activity may result, causing flight of ideas and impaired problem solving abilities. The problem of altered activation, as a result of neurological damage, is extremely important and must be addressed within the context of rehabilitation.

Temporal coordination

Two temporal mechanisms are proposed by von Steinbuchel and Poppel (1993) which serve different but highly related functions. The first is important for the interaction of different functions within the brain. The different activities which are separated either spatially or by different neuronal programmes, but which occur simultaneously, must somehow be integrated. It can be logically assumed therefore, that there is a mechanism within the brain which is responsible for the temporal organisation of the various cognitive functions. The mechanism is therefore responsible for relating the different functions to each other, to give the individual a unified experience in time. An example of the involvement of this temporal mechanism would be a situation whereby an individual is watching a bird and listening to it singing. The individual would have to combine the visual information and the auditory information in order to have a comprehensive perception of this situation. Von Steinbuchel and Poppel state that "if there is a disturbance in this temporal reference system, unified mental acts may no longer be possible." (von Steinbuchel and Poppel, 1993, p.4).

The second temporal mechanism proposed, is required for the temporal integration of information collected serially rather than simultaneously. This additional temporal integration mechanism has to be assumed, they argue, in order to integrate information processed in a successive fashion in different sensory channels. For example, if two individuals are talking, it is necessary for them to take in auditory information as well as visual information. The information processed in the visual and auditory modalities must therefore be integrated in order for each individual to have a unified experience. It has been demonstrated in dysphasic patients for example, that this temporal integration mechanism has been disturbed.

Having described exactly what the basic enabling functions are, the researcher will now give an outline of what is involved in the execution of more advanced cognitive functions. The two functions to be discussed are memory and attention. As the primary focus of this study is the assessment of memory functioning, the discussion on memory will precede that on attention.

1.4.3 The 'what' - The more advanced cognitive functions - memory and attention

MEMORY

Definition of Memory

In the broadest sense, memory refers to the ability to learn new information and to retrieve previously learned information. This can be further defined as memorising, storing and remembering (Auerbach, 1986). Plato differentiated between these three fundamental aspects of memory over two thousand years ago. He used analogies to describe them in the following way:

1) Registration - whereby the bird is put in a cage.
2) Retention - where the bird has to be kept there, alive.
3) Retrieval - where the bird must be successfully caught again.

(Bradshaw and Mattingley, 1995)

Registration and retrieval are the components involved in **learning.** Learning is defined as 'the process of acquisition' which may be measured by the rate at which recall improves in relation to the successive representations of the same material. Learning is impaired by all forms of brain damage (Hebb, 1949) and is thought to be particularly sensitive to temporal lobe damage (Bradshaw and Mattingley, 1995). Registration and retention are also involved in memory, "the persistence of learning in a state that permits subsequent retrieval" (Bradshaw and Mattingley, 1995, p.208). Memory is generally assessed in terms of how much can be recalled after presentation of the material, either by immediate or delayed recall.

Within the field of cognitive psychology, there are three types of memory (Della Sala and Logie, 1993) as follows:

1) Sensory information storage
2) Primary working or short term memory - the output system
3) Secondary, associative or long term memory.

Working memory and long term memory are the the most important systems in terms of memory assessment and rehabilitation, and will now be looked at in more detail.

Working Memory

Working memory involves the integration of sensory perception with long term memories and is vital for success in numerous cognitive tasks, including reading, counting, telephoning and calculating (Bradshaw and Mattingley, 1995). Working memory mediates between memory and action and, according to Baddeley (1992), consists of a central controller, or executive, with a group of underlying (slave) systems. The two most important slave systems are :

1) An inner speech mechanism, responsible for the silent rehearsal of verbal information (the articulatory or phonological loop)
2) A visuospatial "scratch pad", responsible for the imprinting of visual information.

(Bradshaw and Mattingley 1995)

The whole working memory system allows us to develop conscious, introspective thoughts, ideas, and plans for the future. Bradshaw and Mattingley comment that the "entirely unconscious contents of long term memory (LTM) are only of use if they can be appropriately assembled in working memory to meet current environmental demands." (Bradshaw and Mattingley, 1995, p.211). Working memory is not localised as such, but it can be concluded from research "that working memory depends upon a variety of networked brain areas, depending upon task, stimuli and strategy........the prefrontal regions are involved in an overall executive or supervisory fashion, coordinating and controlling working memory functions." (Auerbach, 1986, p.9) This obviously relates back to the enabling functions which are responsible for the integration of different functions within the brain. 'Working memory' therefore involves processing within several different brain regions, rather than being a localised function. The frontal lobes and the hippocampus however, are particularly important at this level of processing (Olton, 1983).

The term 'working memory' is used by virtue of the fact that this construct relates to the amount of information that is retained for the duration of time that it is consciously attended to. This construct is now considered to be an aspect of attentional functioning, rather than memory, per se. Auerbach (1986) refers to working memory as 'attentional capacity.'

Long Term Memory

Long term memory refers to the ability to memorise, store and remember over longer periods of time than are involved in working memory.

There are three main areas of the brain involved in long term memory:

1) The medial temporal lobe, hippocampus, amygdala and associated limbic regions, which constitute part of the old circuit of Papez.
2) The thalamus and mamillary bodies.
3) The basal forebrain.

(Bradshaw and Mattingley, 1995)

The medial temporal lobe and associated subcortical structures, especially the hippocampus, are responsible for storing and consolidating new memories and retrieving old information.

The system may be particularly important for autobiographical memories that can be put into propositional form. Damage to this system is likely to affect recall of information more than any of the other aspects of memory. Acquisition and retrieval of skill memory (the memory of how to carry out procedures) are relatively unimpaired. Tacit/implicit learning, problem solving and recognition memory are also more or less unimpaired.

Verbal LTM is most sensitive to damage in the left frontal and medial temporal lobe areas, whilst non-verbal or visual memory is most sensitive to right frontal and anterior temporal damage. Verbal STM is affected by left parieto-occipital lesions and frontal lesions.

Overall, far more is known about the neuropsychology of long term memory than working memory. The literature concerning the many different aspects of memory functioning is generally in agreement. There is a great deal of disharmony in the literature however about the complexities of the attentional system.

ATTENTION

Definition of Attention

Numerous definitions of attention have been reported in the literature, but these are often disparate or conflicting and there is no universally accepted definition (Lezak, 1995). For example, Mirsky (1989) viewed attention as being a subcomponent of an information processing system, whereas Gazzaniga concluded that "the attention system....functions independently of information processing and [not as]..... an emergent property of an ongoing processing system." (Gazzaniga, 1987, p.126). Lezak suggests that "...attention refers to several different capacities or processes that are related aspects of how the organism becomes receptive to stimuli and how it may begin processing incoming or attended to excitation (whether internal or external)." (Lezak, 1995, p.39). One aspect of attention that is agreed upon, is the differentiation between involuntary and voluntary attentional processes. As far back as 1890, William James differentiated between 'reflex' (automatic) attentional processing and 'voluntary' (controlled) attentional processing. This differentiation is fundamental to our present understanding of the attentional system.

Automatic/involuntary attentional processing

Niokiktjien (1988) refers to uncontrolled diffuse attention for background aspects in the environment, which is synonymous with James' concept of automatic attention. This is the attention for information that is not relevant but that is registered within the brain nevertheless. It results in incidental learning rather than intentional learning.

McGuinness and Pribram (1980) similarly differentiate between involuntary and voluntary attention and discuss two separate aspects of attentional control. In relation to physiological studies, they discuss two involuntary modes of attention: *arousal and activation.* This relates to von Steinbuchel and Poppel's concept of the 'how' functions, as discussed earlier in section 1.4.2. (von Steinbuchel and Poppel, 1993), as arousal and activation are necessary prerequisites for more advanced cognitive functioning. McGuinness and Pribram (1980) define arousal as a short-lived, reflex response to input. The second stage, activation, is defined as a long-lasting, involuntary readiness to respond. A third system, concerning *effort,* is suggested to coordinate arousal and activation and result in voluntary control. This concept of effort is a simplified version of von Steinbuchel and Poppel's temporal coordination mechanisms (von Steinbuchel and Poppel, 1993). McGuinness and Pribram (1980) suggest that arousal occurs when perceptual input is unexpected, complex or novel. Activation differs from arousal in that it maintains the potential to continue behaviour, that is, the maintenance of readiness to respond.

It is apparent that arousal, activation and effort are all extremely important in relation to the process of attending to internal or external stimuli. It is important to remember that a common consequence of most forms of neurological insult, is a *reduction* in cerebral arousal and activation (Rose, Attree and Johnson, 1996). The reduction in cerebral arousal and activation may combine with other impairments, for example in memory, motivation and high level controlled attention, to adversely affect the brain injured individual's ability to function.

In the current study, the issue of reduced arousal and activation is important in relation to the subjects' abilities to execute attention and memory processes. This is particularly pertinent to those who had experienced neurological insult most recently, that is , those whose levels of activation and arousal are likely to be most significantly reduced. It also relevant however, for those who took part in the study, who continue to be affected by reduced activation and activity levels some time after their neurological insult.

Controlled attentional processing

Controlled attention is a complex concept supraordinate to that of automatic attentional processes. There is also far more disagreement in the literature concerning the different aspects of controlled attention.

Attention is generally conceived of as a system in which processing occurs sequentially and with the involvement of different brain systems (Butter, 1987; Mirsky, 1989; Sheer and Schrock, 1986). The attention system appears to be organised in a hierarchical manner with different systems controlling different aspects of attentional functioning (Posner, 1978). Recent PET studies have provided the strongest support that attention is fractioned into different systems, and that these systems are localised seperately within the brain. Attentional deficits may occur as a result of lesions at any point in these systems.

The attentional system has a limited structural capacity (Gazzaniga, 1987; Posner, 1978), which restricts the amount of processing that can occur at any one time. Attentional processing at one level may interfere with attentional processing at another level if that capacity is breached. For example, it may be impossible to concentrate on news on the television while also listening to the radio, as both activities would necessarily require the involvement of the same attentional subsystems. It is possible however, to drive a familiar route while carrying out a conversation. This latter situation is possible because very little demand is made of attentional subsystems in order to carry out a relatively automatic task, such as driving a familiar route. The individual is therefore more able to attend to the conversation.

Subcomponents of controlled attention

Lezak writes about 5 aspects of controlled attention, as described below. The first aspect of attention is relatively resilient in relation to neurological insult. "The other four aspects of attention are more fragile and are therefore of greater clinical concern" (Lezak, 1995, p.39).

1) **Immediate span of attention** is the amount of information that can be grasped at once and does not require much effort. As mentioned earlier, this is often considered as a form of

memory, (working memory), but is an integral part of attentional functioning (Howieson and Lezak, 1994).

2) **Focused** or **selective attention** is "the capacity to highlight the one or two important stimuli or ideas being dealt with while supressing awareness of competing distractions" (Lezak, 1995, p.40). This is often referred to as *concentration.* Some researchers further distinguish between focused and selective attention, but for the purposes of this study, Lezak's description is sufficient. There is evidence for a functional-anatomical specialization of selective attention. Activation of the anterior cingulate area of the frontal cortex has been demonstrated during performance of a classic selective attention task - the Stroop Test (Bench, Friston, Brown, Frackowiac and Dolan, 1993., Pardo, Fox and Raichle, 1991). The thalamus is believed to be the 'gating system' that selects and then filters information that may or may not proceed for further processing (Mateer and Ojeman, 1983).

3) **Sustained attention** or **vigilance** refers to the ability to carry out attentional processing over a period of time (Sheer and Schrock, 1986; Stuss and Benson, 1989). Evidence exists for localisation of sustained attentional processing to the right frontal parietal area (Pardo, Pardo, Janer and Raichle, 1990; Whitehead, 1991; Wilkins, Shallice and McCarthy,1987).

4) **Divided attention** involves the ability to carry out more than one task at a time or to respond to different aspects within a complex task. Divided attention is required when two or more simultaneous processes need to be carried out, for example, talking while driving. As mentioned earlier however, if one of the processes being carried out is an overlearned behaviour, then this may be accomplished quite easily. The overlearned behaviour is more automatic, requiring less effortful processing.

5) **Alternating attention** allows individuals to shift their focus of attention. This involves switching between tasks with different cognitive demands or requiring different behavioural responses. In this situation, the individual must monitor which information will be attended to or which responses are appropriate. Clinical studies of response patterns on tests such as the Wisconsin Card Sorting Test suggest that alternating attention involves the dorsolateral prefrontal cortex.

Activity Rate

One final factor which contributes to the individual's ability to carry out attentional processing, and all other aspects of cognitive functioning, is activity rate. This refers to the speed at which cognitive functions are performed and to motor response speed. Activity rate therefore, is synonymous with what other investigators have referred to as 'speed of processing' or 'information processing speed'. The literature varies as to whether speed of processing is an aspect of attention or whether it is separate from attentional functioning, but with great implication for attentional success. Activity rate is an important consideration in this study as, whether or not it is part of the attentional system, it will have implications for memory functioning, as well as for the five different components of attentional functioning as described above. Lezak (1995) reports that many patients' attentional disorders are indeed due to slowed activity rate.

Slowed motor response is commonly seen as a result of normal ageing or brain damage (Stuss, Stethem and Hugenholtz, 1989) and may occur in relation to muscular weakness or poor coordination. Slowing of mental activity can be most obviously noted in delayed reaction times and in total performance times that are significantly longer than average, when the individual being assessed does not have any specific motor disability.

1.4.4 Interaction between memory and attention

Whilst attention and memory functions are differentially organised within the brain, they do not operate in isolation, but are interdependent to some extent. Interaction may be critical for efficient processing to occur (McGuinness and Pribram, 1980).

According to Njiokiktjien (1988), the neurophysiological arousal mechanisms concerning attention are mainly functions of the brain stem and the frontal lobe, which channel the perception, selection and storage of information into the parietal, temporal and occipital areas. Arousal mechanisms play a role in voluntary activity controlled by the pre frontal areas. Perceptual stimuli are processed simultaneously in both hemispheres at a lower, subcortical level, or the "precategorical level" (Njiokiktjien, 1988, p.225). However, the complexity of the information determines in which of the hemispheres the emphasis subsequently lies. Categorical information is processed partially and then access is gained to the hemisphere that is specialised for that particular kind of information (Moskovitch, 1979). The processing of categorical information takes place in *working memory.* Interhemispheric interaction is inherent to attention and information processing.

A distinction is generally drawn between three functional stages of memory: the encoding stage (for which short term memory is necessary), retention or storage (things are maintained in LTM) and reproduction or retrieval (things are recovered from memory, recalled, remembered or reorganised). Short term and long term memory are essential components of learning mechanisms and there is strong evidence that they are functionally separated. STM is often impaired in some individuals while the LTM can be intact, or the other way round.

The relation between attention and memory is not precisely defined. Attention can be seen as the ability to deal efficiently with memory functions. Njiokiktjien (1988) states that the capacity of the working memory determines the optimal quantity of attention that a person can devote to a task. People can generally retain up to seven chunks of information at a time. The overall speed of memory processing is determined by several factors, one of which is the actual time taken to retrieve memories. Memory retrieval is slower in young children, for instance, than it is in adults. It is understandable therefore, that the ability to focus attention on the memory task at hand, is related to retrieval. An individual's ability to *attend* to information therefore will greatly affect the individual's ability to *remember* that information. Fisk and Schneider (1984) provide evidence that the *amount* of attentional capacity that is allocated to stimuli determines how well subjects will be able to recognise those stimuli. A reasonable conclusion therefore is that "the acquisition of new information is strongly dependent on attentional processing" (Nissen, 1986, p.19).

Long term memory for all sensory modalities is assumed to be localized in the secondary and tertiary cortices of the brain. Imprinting and retrieval takes place with the help of the limbic system memory circuits. Njiokiktjien (1988) states that attention and memory actually coincide in the limbic system. When a memory is encoded, it is assumed to take place in cell assemblies rather than individual cells. The memory can then be aroused by retrieval mechanisms of the limbic memory circuits. Pribram (1971) compares the memories we have stored away to holograms. The analogy here is that holograms remain intact even if parts of them are removed, because the information is stored in every point. He supports his hypothesis with many arguments, the most pertinent of which, for current purposes, is the brain's 'functional anatomical redundancy' (Pribram 1971). He is indicating here, that a great deal of brain tissue has to be lost before memory is lost. This obviously relates back to the concept of brain reserve capacity as discussed in section 1.2. If a lesion results in the damage of a particular part of the brain therefore, this does not mean that part of the memory is lost. A certain threshold must be reached for an individual with neurological damage before any cognitive deficits/functional impairments become apparent. We know however that memory for a particular category is often linked to a certain hemisphere or cerebral lobe, rather than being diffusely distributed throughout the whole of the brain.

1.5 NEUROPSYCHOLOGICAL ASSESSMENT OF COGNITIVE FUNCTIONING - THE IMPORTANCE OF ECOLOGICAL VALIDITY

As described above, various types of deficits have been reported after brain damage, in the areas of memory, attention, perception, reasoning, language and executive functioning. Rather than simply evaluating the functional consequences of neurological impairments however, neuropsychologists are involved in cognitive retraining and the development of compensatory strategies. An appropriate and accurate assessment of cognition is essential for the planning and implementation of rehabilitation.

The most widely used measures for cognitive assessment tend to be paper and pencil type tests that are carried out in a clinical setting. Research over the past twenty to thirty years however, has suggested that such standard clinical methods of assessment may not relate to how individuals actually function in their everyday lives. Neisser referred to psychology's "thundering silence" about memory functioning in everyday life (Neisser, 1978, p.4).

> "The fact is that we have almost no systematic knowledge about memory as it occurs in the course of everyday life. Almost all the phenomena that a contemporary theory must explain are highly artificial: recall of word lists or nonsense syllables, identification of photographs that were included in a long series inflicted on the subject earlier on .... Until we know more about memory in the natural contexts where it develops and is normally used, theorising is premature." (Neisser, 1976, p.141-142)

Neisser felt that "cognitive psychologists must make a greater effort to understand cognition as it occurs in the ordinary environment and in the context of a natural purposeful activity. This would not mean an end to laboratory experiments, but a commitment to the study of variables that are ecologically important rather than those that are easily manageable." (Neisser, 1976, p.7)

Because of the changing role of neuropsychological assessment, the nature of referral questions has also changed, and new areas must now be addressed. For instance, with the increasesd emphasis on cognitive retraining and the development of compensatory strategies, neuropsychologists are now being asked to make statements regarding functional skills, treatment options, rehabilitation potential and optimal living arrangements (Henrichs, 1990). An important consideration relates to what the neuropsychological tests actually measure and what questions are to be addressed. There is an increasing emphasis on the evaluation of present cognitive functioning and relating this measure to an unknown premorbid level of functioning or to future performance. It is this latter question that is most pertinent to the current study. Neuropsychologists are increasingly being asked, for example, to give advice regarding expected future performance of individuals at work or in school. Long (1996) proposes that in both of these instances neuropsychologists lack empirical data and therefore end up making predictions that they are unable to back up with research.

It is accepted that standard neuropsychological assessments can give clinicians information about the *nature of cognitive deficits* and give some idea of the likelihood of problems in everyday life. Competent psychologists who have worked in the area for many years have gained valuable experience which enables them to give some indication as to the type of problem the patient is likely to encounter in everyday situations. It is therefore possible to make useful suggestions about rehabilitation or how the individual should manage the expected difficulties. Clinical judgement and experience in neuropsychological assessment issues are obviously useful when making predictions about future levels of functioning, but the vital criticism here is that such predictions have little or no *empirical foundation.* The main criticism of standard neuropsychological tests therefore is that they are lacking in ecological and predictive validity.

In terms of assessing memory impairment, Mack points out that as "cognitive tests tend to be complex multifactorial tasks it is difficult to interpret research findings limited to a single or small set of procedures." (Mack, 1986, p.29) Patients may gain similar scores on the same tests while actually experiencing very different types of memory deficits. Others may achieve relatively normal scores on memory tests by using strategies that circumvent the impairment. There is considerable interaction between memory and attention processing which complicates the interpretation of assessment results (See section 1.4.4.).

The criticism of neuropsychological measures having poor ecological validity also applies to measures of attention. Kerns and Mateer (1996) point out that an individual may perform poorly on standard tests of attention yet go on to function well in everyday tasks. Conversely, they note that individuals may do well on tests of attention but function extremely poorly in their everyday lives. They go on to say that, "to get a better understanding of how everyday life and measures of attention relate, it is imperative to know what different tests of attention actually measure." (Kerns and Mateer, 1996, p.157) There is a wide variety of standard clinical tests used to gain information about individuals' attentional processing. However, the absence of cohesive tests to look at all the subtypes of attention means that "relatively little is known about the clinical correlates of attentional problems and about their prognostic significance following brain damage." (Kerns and Mateer, 1996, p.161)

By comparing two cases, Wilson (1993) gives an excellent illustration of how the information gained from neuropsychological tests may be inadequate in predicting future behaviour. LE sustained a brain haemorrhage while an undergraduate student. He experiences severe memory difficulties as a result of this. Nevertheless, he lives alone, is in paid employment and is independent in all activities of daily living. VK, on the other hand, has completed the same memory tests and is reported to have a mild memory impairment. She is unemployed however, and needs assistance with most activities of daily living. The information about these two cases seems inconsistent, until it is clarified that LE has no other cognitive difficulties whereas VK has sustained a severe injury resulting in diffuse damage. She has problems in several areas of cognitive functioning, including perceptual, word finding, reasoning and organisational difficulties. These deficits prevent her from compensating for, or bypassing, her relatively mild memory problems.

1.5.1 Definition of the term "Ecological Validity"

The issue of *ecological validity* is of great importance in relation to predictions regarding the future performance of individuals who have suffered any form of neurological insult. There are two aspects of ecological validity, that need to be considered. The first is the extent to which assessment measures carried out in a clinical setting are similar to behaviour carried out in the individual's natural environment. Franzen and Wilhelm (1996) refer to this as 'verisimilitude'. The second aspect of ecological validity is the extent to which the individual's performance on clinical assessments will predict his/her level of functioning in the natural environment. This is referred to as 'veridicality' (Franzen and Wilhelm, 1996). Implicit within the term 'ecological validity' is the idea that the assessment procedure is *similar* to the natural behaviour in the real world and that the assessment results can therefore *predict* the natural behaviour in the real world (Franzen and Wilhelm, 1996). Sbordone defines ecological validity as the "functional and predictive relationship between the patient's performance on a set of neuropsychological tests and the patient's behaviour in a vatiety of real life settings eg, at home , work, school, community." (Sbordone, 1996, p.16)

The ideas of verisimilitude and veridicality are therefore both implicit within the term 'ecological validity'. Veridicality is the most important of these two aspects however, as it concerns the extent to which the neuropsychologist can use assessment measures to predict the individual's level of functioning in the future. It can be argued quite simply that verisimilitude is of less importance. It is foreseeable after all, that a particular neuropsychological assessment measure could have a high degree of veridicality (predictive power) without it being similar to the actual behaviour being carried out in the natural environment. One example of this is the apparent predictive power of the second part of the Trail Making Test. The second or 'B' part was found to be among the best predictors of ability to drive in brain injured drivers (Hale 1986). This may seem rather incongruous since the behaviour required to complete Trails B does not, at first inspection, bear any resemblance to the actual behaviour involved in driving. It can be understood nevertheless that the behaviour assessed by a cognitive test need not be similar in appearance to the real life behaviour. An alternative way of looking at the importance of veridicality versus verisimilitude is that, if an assessment measure starts off as being similar to particular behaviours in the natural environment, then it is *more likely* to have greater predicitve power.

Long states that it is vital to consider the relationship between the assessment measure being used and the behaviour being predicted. "Ecological validity suggests that the accuracy of prediction of future behaviour is further influenced by the extent to which the test score relates to the behaviour to be predicted." (Long, 1996, p.10). The confidence here relates to the confidence we have in the similarity between the skills required for the assessment procedure and the skills required to carry out the behaviour in the open environment. No neuropsychological assessment can answer this question better than the direct measurement of performance in the open environment. Long proposes that the most *indirect* measure of obtaining information about real world behaviour is psychometric tests, yet they represent the main source of information for most neuropsychological evaluations. "Psychometric tests represent samples of behaviour in a reasonably controlled situation which may have a relationship to daily behaviours in other situations. However, in almost all cases, it is a sample that only represents a part of the criterion behaviour to be predicted" (Long, 1996, p.11).

The present study is concerned with both of these aspects of ecological validity. Veridicality however is believed by the current researcher to be more important in terms of the prediction of future levels of functioning. As mentioned earlier however, it logically follows that the greater the degree of verisimilitude, then the greater the degree of veridicality. The VR assessment measure is believed to have validity in terms of both of these aspects. This will be discussed further in section 1.7.

The validity of an assessment instrument is generally related to the ability of that instrument to answer the questions being asked of it. Ecological validity therefore is not an important consideration in all assessment techniques. For example, when the main question posed is the localisation of a lesion, ecological issues are not particularly relevant. If the question being asked however, concerns the issue of an individual's probable level of functioning in future, then ecological issues become important.

Long (1996) proposes that if neuropsychologists are asked about prognosis, they must draw on known relationships of change in cognitive functioning and subsequent recovery in other groups of patients with similar etiology and time since injury. This, he proposes, is relatively easy in cases where the dysfunction is either very extreme or nonexistent, but that it becomes more difficult at mild to moderate levels of dysfunction. He proposes that if the overall level of functioning is markedly impaired or is well above average, the prediction of behaviour is more accurate. Thus, as the individuals' abilities approach the mean, the ability to predict behaviour is reduced and is more likely to be influenced by other factors. Long stresses that it is imperative for neuropsychologists be aware of existing data and not go beyond it or, if they do, they must be careful to make a statement regarding the "reduced probability of their conclusions." (Long, 1996, p.7)

Wedding and Faust (1989) discuss prediction further, arguing for an awareness of a number of corrective procedures, including:

1) know the literature on the fallibility of human judgement
2) start with the most valid information

3) collect appropriate norms

4) make a deliberate effort to obtain feedback.

Whether or not these suggestions are taken literally, the main issue is that the neuropsychologist should make three statements; what the prediction is, what its foundations are, and the degree of confidence in the prediction.

1.5.2 Standard Clinical Assessments - poor predictors of real life functioning

Several studies have addressed the question of whether or not standard neuropsychological tests are useful as predictors of real life functioning. The most optimistic findings were reported by Ryan, Sautter, Capps, Meneese and Barth (1992). They found that standard neuropsychological assessments were highly accurate in predicting whether subjects would successfully complete a vocational evaluation. The best predictors were reading comprehension, immediate and delayed verbal memory, depression and dysphasic symptomatology.

In contrast, the majority of the literature indicates that clinical assessments are *poor* predictors of performance in real life situations. Hart and Hayden (1986) summarised the research concerning correlations of patients' performance on neuropsychological tests and their behaviour in real life settings. They concluded that "our systems for classifying and describing (ie. measuring) the behaviours related to brain injury do have predictive power for localizing an injury, but apparently less for understanding its effects on adaptive functioning." (Hart and Hayden, 1996, p.32) By carrying out a detailed assessment therefore, neuropsychologists can find out which areas of the brain are malfunctioning. This information is found to be relatively unhelpful however, in predicting the future difficulties that patients may encounter.

The literature suggests that, for activities of daily living, complex tests appear to have greater predictive power than do simple tests. The Halstead Category Test (Halstead, 1947) is a complex problem solving task which has a high predictive power (Goldstein, 1996). Simple tests, concerning more basic perceptual and motor abilities tend to have correspondingly less predictive power. This makes logical sense in that activities in the real world are likely to involve the interaction of different cognitive functions and the execution of different behavioural responses. Complex neuropsychological assessments should therefore be more likely to correlate significantly with real life abilities because of their multifactorial nature. Acker and Davis (1989) carried out correlational analyses of several neuropsychological tests and functional outcomes in real life. The correlation between the memory quotient of the Wechsler Memory Scale and a global measure of functional outcome was -0.48 ($p<0.001$). The correlation of the global functional outcome with the colour recognition component of the Stroop test was -0.16 ($p>0.05$). Goldstein states that "the notion that one can predict performance levels of complex functions from an analysis of what are assumed to be component individual skills has proven to be largely illusory. Thus, tests that may have high relevance as components of the neurological evaluation may have little capacity to predict functional outcome." (Goldstein, 1996, p.79-80)

Detailed reviews of ecological validity studies conclude that reasonable correlations exist between test results and outcome measures (Acker, 1990; Chelune and Moehle, 1986 and Heaton and Pendleton, 1981). Acker reports correlations as high as 0.85, but the explained variance rarely exceeds 40%. Goldstein (1996) notes that no particular tests or test batteries stand out as being superior to others in relation to ecological validity. "Except for the general finding that complex tests tend to be better predictors than simple tests, the superiority of one predictor over another will vary greatly with different patient populations" (Goldstein, 1996, p.84). Overall then, simple neuropsychological tests are poor predictors of real life abilities while complex tests are of more use. There are exceptions to this however. As mentioned in section 1.5.2. Trails B, a cognitive test concerning attention and activity rate, was found to be a *good* predictor of driving ability (Hale, 1986). Also, despite the fact that complex tests generally seem to be better predictors of real life abilities than simple tests, they still only explain a relatively small proportion of the variance in such abilities, leaving ample room for improvement. After all, it makes no sense to continue using neuropsychological tests in an attempt to answer questions about future behaviours, when it is possible that alternative forms of assessment may explain more of the variance. One such alternative is the use of VR technology. VR as a means of neuropsychological assessment shows a great deal of promise, particularly in relation to the issue of ecological validity. The present study is the first step in comparing the utility of VR and standard clinical measures in the assessment of cognitive functioning after neurological damage.

1.5.3 Suggestions for improved ecological validity within neuropsychological assessment

Goldstein (1996) states that neuropsychological tests are poor surrogates for direct measurement of actual abilities and behaviours in the real world. A test can assess an ability but is not the ability itself. The question raised therefore is how assessments can become more ecologically valid. Goldstein (1996) points out that most tests were not meant to be ecologically valid, but were often designed to determine whether or not individuals were suffering from some sort of cognitive deficit, and to localise the lesions. Tests were generally evaluated against neurosurgical or radiological data. Goldstein suggests that it would be more productive to design tests with ecological validity in mind. The Rivermead Behavioural Memory Test (RBMT) (Wilson, Cockburn and Baddeley, 1985) is cited as the best current example of this effort. Goldstein suggests that the RBMT may be ecologically valid not because of the practical nature of some of the items but because from the beginning, the development of the test was oriented towards prediction of behaviour in real life settings. It was derived from a checklist of patients' and informants' reports about various memory problems (Sunderland, Harris and Baddeley, 1984).

Many studies have used patients' self report measures of difficulties experienced in everyday situations. These have been found to be unreliable however as brain damaged patients tend to be poor informants concerning their own abilities and difficulties. In a recent study, Goldstein and McCue (1992) reconfirmed the finding that patients were, in general, poorer judges of their own capacities than objective observers. Rather than using patients' self report measures, tests which are designed to be ecologically valid should be validated against the reports of objective observers, as in the RBMT study (Wilson et al 1985).

The main premise therefore is that new tests should be developed which are neuropsychological in nature, but that are also relevant to real life. The VR assessment being used in the current study has been designed with ecological criteria in mind, in that it involves the simulation of four rooms representative of rooms in the natural environment of the patients. The VR assessment also involves interaction with the virtual environment, akin to individuals interacting with the real environment as a necessary aspect of real life. The issue of validating new assessments against ecological criteria is also addressed in the current study whereby the VR assessment is validated against the memory failures checklist (Sunderland et al, 1984, **see appendix 3)** and the RBMT. The memory failures checklist is completed by carers/relatives of the brain injured and it is therefore an objective measure based on direct observation.

1.5.4 Criticism of the Rivermead Behavioural Memory Test

The RBMT has excellent face validity as the subtests are all designed to relate to realistic tasks in everyday situations, thus meeting the criteria for verisimilitude. However, the RBMT does not have a strong theoretical basis and is possibly too far removed from the application of cognitive psychology to clinical practice. Whilst the Rivermead subtests appear to relate to real life situations, the summed screening score or profile score may not yield sufficient information about which neurological systems are impaired. It is suggested that using an overall memory score, similar to the memory quotient in the Wechsler Memory Scale may be useful for predicting future performance, but is unhelpful for the clinician who strives to understand the neurological deficits in different memory systems. The subtest scores can obviously be looked at individually, but again, there are problems in interpretting the scores in a sense that is clinically useful in terms of rehabilitation. In order for a memory assessment to be of maximum clinical use, the subtests of the assessment battery should relate clearly to the different levels of processing, so that the neuropsychologist can make sense of how these memory deficits relate to the functional-anatomical organisation of the brain.

Another criticism is that the RBMT is used purely as a test of memory with no consideration given to the role of attention in memory functioning. As has been described in section 1.4.4, memory and attention are inextricably linked. An assessment that fails to consider the attentional component in everyday memory functioning therefore, is surely flawed. An assessment using the RBMT alone could give false information regarding an individual's cognitive deficits if the memory difficulties were actually due to deficits in attentional functioning rather than deficits in memory functioning per se. A thorough assessment therefore would necessarily require further assessment of attentional abilities using an entirely separate assessment measure. The current researcher is not suggesting however that Wilson et al (1985) intended the RBMT to be used as an assessment measure in isolation. The main proposal is that an assessment measure based on interaction with a VR environment may give far more comprehensive information concerning multifaceted cognitive functioning rather than having to use different measures developed by different researchers. This optimism regarding the usefulness of VR in assessment of cognitive difficulties after neurological insult will be discussed more fully in section 1.7.

1.6 VIRTUAL REALITY AND ITS MANY POTENTIAL APPLICATIONS

A recent European conference on disability, virtual reality and associated technologies concerned the use of VR for many diverse purposes including teaching communication and language, adapting environments for disabled people, medical treatment, and the generation of virtual acoustic environments for blind people. The most relevant literature in relation to the current study, is that concerning VR in neurological rehabilitation. Research is *beginning* to addess the issue of VR within the field of rehabilitation after brain injury. This is an extremely new area of research, but results so far suggest that it may be an extremely effective form of rehabilitation (Johnson, Rushton and Shaw, 1996). It is suggested that interaction with the environment is the critical factor in effecting changes in functioning (Rose et al, 1996a).

Animal studies have demonstrated that increased levels of interaction with the environment result in a more highly developed and more efficient brain (Renner and Rosenweig, 1987) including ".......a greater amount of cerebral cortex, more profuse connections between cortical neurons, increased activity in glial cells and a higher metabolic rate within the cerebral cortex. Increased environmental interaction has also been shown to enhance functional recovery following many types of brain damage in animals" (Rose et al, 1996b, p.225). Although conventional therapies such as physiotherapy, occupational therapy and speech therapy inherently involve increased levels of interaction with the environment, relatively little time is actually spent in formal therapy. Tinson (1989) for example, reports that stroke patients spend between 30 minutes and 1 hour in therapy each day. Consequently, there are likely to be lengthy periods in the patient's day when environmental interaction is at a lower level than is therapeutic for that individual. Rose et al (1996b) suggest that VR provides an excellent way of increasing patients' levels of environmental interaction.

Johnson et al (1996) propose that the whole area of neurological rehabilitation must be changed. They point out that "the practice of neurological rehabilitation has seen little significant change for the better since the turn of the century...." and that ".....there remains an overall scepticism of therapeutic efficacy." (Johnson et al, 1996, p.247) The main criticism of current neurological rehabilitation is that therapists focus on specific problem areas such as memory or activities of daily living. Johnson et al propose that there should be a greater emphasis on the underlying neuropathophysiological factors rather than on the outward manifestations of neurological damage. It is suggested that therapists should concentrate on the "underlying and general depression of the cerebral activation" (Johnson et al, 1996, p.248). The main premise of virtual reality in neurological rehabilitation therefore, is that it addresses the issue of decreased behavioural interaction after neurological insult and subsequently increases cerebral activation.

There are different levels of sensory immersion within virtual reality systems. Larijani (1994) refers to these as immersion at the levels of space, object or environment. The simplest level concerns observation of three dimensional space. At the object level, the individual can interact with the three dimensional space, thus incorporating a deeper level of immersion. The environment level concerns total immersion whereby all references to the real world are blocked out and are replaced by substitute visual, auditory and tactile stimuli. Most of the research concerning rehabilitation after neurological damage has used immersion at the second level. Although total immersion would obviously give the most relaistic sort of environment, it would not be feasible to carry this out with brain injured individuals as immersion at this level may affect visual and vestibular functions to induce nausea and feelings of being off balance (referred to as 'simulator sickness', Rose et al, 1996b). The technology involved in full immersion VR is also extremely complex and very costly.

The use of virtual environments rather than real envionments has many advantages, the most obvious of which are the greater accessibility, safety and diversity of the virtual environments. Many different environments can be presented by the computer software design and the patients therefore do not need to be moved physically. The virtual environment can also be manipulated to make particular demands of the patients, which would be less easy to do in the real world. A virtual reality programme can therefore be adapted to meet the needs of individuals in order to maximise their abilities after neurological damage.

1.7 VIRTUAL REALITY- AN INNOVATIVE FORM OF NEUROPSYCHOLOGICAL ASSESSMENT

Research has of yet given little consideration to the use of VR in the *assessment* of cognitive functioning after brain injury. Andrews, Rose, Leadbetter, Attree and Painter (1995) suggested that assessment of cognitive functioning may be more valid if carried out in a controlled manner but within the context of a realistic everyday environment. This is particularly pertinent within the context of ecological validity, as discussed earlier. Andrews et al (1995) conducted a preliminary study, comparing university students' incidental memory for objects presented in a virtual environment (domestic rooms) and static computer displays. Superscape Virtual Reality Software was used to create a virtual world of four rooms, with objects from the Superscape library presented within the rooms. 100 students took part in the study and were randomly allocated to 5 different object presentation conditions as follows:

1) Objects presented in interactive virtual rooms.
In this condition the objects presented to subjects were contained within a virtual house consisting of four interconnected rooms. Subjects were instructed to move through each room in turn.

2) Objects presented in static displays (no context).
Subjects in this condition were presented with four consecutive static displays on the computer screen. These displays consisted of the objects from the four virtual rooms but were presented without any background context. Subjects were simply instructed to look at each display.

3) Objects presented in the context of static pictures from the virtual rooms.
Objects were contained in a series of 4 consecutively presented static computer pictures taken from the doorways of the virtual rooms used in condition 1. The objects were presented within the same visual context but without any interaction. Subjects were instructed to look at each picture.

4) Objects presented in the context of static pictures from the virtual rooms - with motor task.
The displays of objects in this condition were the same as for condition 3, but subjects were asked to move the cursor over each of the objects.

5) Objects in static displays (no context) - with motor task.

The displays here were the same as in condition 2 but subjects were asked to move the cursor over each of the objects.

Subjects were not instructed specifically to memorise the objects. Rather, memory for the objects was assessed using a recognition task given after a short delay. Andrews et al (1995) found that performance in the first condition was significantly lower than in any of the other four conditions, indicating that the addition of a motor task to the typical laboratory situation had a significant detrimental effect on memory. That is, when the individuals actively negotiated their way through the environment, their memory scores were lower, presumably because they could not give as much attention to the objects on display as they were also attending to the motor component.

In a second experiment, Andrews et al (1995) used the same virtual rooms and objects but, this time, the subjects were in 'yoked pairs', tested in adjoining rooms. They found that subjects who interacted with the virtual environment performed at a lower level on the test of incidental memory than their passive yoked controls who were exposed to exactly the same virtual environment. This again can be attributed to the fact that the active individuals are attending to the motor task as well as to the environment, thus dividing their attention.

Andrews et al concluded from these two experiments that the VR methodology had allowed them to "assess the effects of incidental memory of real life factors such as meaningful pictorial context, motor activity and interaction with the environment", in a completely controlled test situation (Andrews et al, 1995, p.279). This innovative research has not yet been extended to examine the usefulness of virtual reality in the assessment of neurologically impaired individuals. The VR assessment used in this study, as in the study carried out by Andrews et al (1995), involves immersion at the second level; the object level, as outlined in the previous section.

As VR has never been used as a means of cognitive assessment in the brain injured population, it is necessary to address whether or not this form of assessment is evaluating the same cognitive functions as are standard clinical assessments. The present study aims to address this issue of concurrent validity by correlating performance on a number of neuropsychological tests with performance on the VR assessment. Concurrent validity concerns the extent to which different assessments are measuring the same construct(s). In the current study, correlations were computed concerning the scores on the VR tasks and the scores on several other memory assessments to determine the extent to which the VR tasks are measuring the same aspects of memory as these other tests. Despite being an overtly visual task, subjects are likely to verbalise the names of the objects, presented within the virtual environment, in order to aid recall, therefore placing more emphasis on verbal memory than visual memory.

The current study is concerned with explicit memory rather than the implicit memory function studied by Andrews et al (1995). Subjects in the current study therefore, were instructed, prior to starting the VR tasks, to remember as many of the objects as possible.

The issue of ecological validity is of particular interest in the current study. It is proposed that the VR assessment will be more valid than standard memory assessments, at predicting memory difficulties in real life situations because the VR assessment involves interaction with an environment similar to the real world. Because of the verisimilitude inherent within the VR task, it can be therefore be argued that the VR assessment will be particularly useful in predicting actual levels of functioning in the real world. That is, the VR assessment should have a high degree of veridicality.

While neuropsychological tests are used to assess particular cognitive processes, each test invariably measures a number of broad constructs such as attention, perception, memory and language skills. In addition, higher cognitive processes influence other functions and vice versa (Long, 1996). For example, a memory assessment instrument may measure some aspects of memory; but memory itself is likely to be influenced by other factors such as attention, language function, emotional status, and so on. Similarly, deficits in memory are likely to affect performance in these other cognitive domains (Long, 1996). The VR memory assessment is no different in this respect, and is likely to involve aspects of cognitive functioning other than memory. Specifically, the VR test should also assess attentional functioning to some degree, because of the demands for attention inherent with VR interaction. The study therefore is looking specifically at the assessment of two broad aspects of cognitive functioning; memory and attention. Divided and sustained attention are the aspects of attention most obviously involved in the VR assessment, that is, the VR assessment requires the individuals to divide their attention between the actual memory task and the motor task. Similarly, the VR assessment requires individuals to maintain attentional activity over a period of time.

As discussed in section 1.5.3, complex forms of assessment are better predictors of future functioning than simple forms of assessment. The VR assessment requires visual processing as well as verbal encoding of information. It also requires the individual to carry out the motor task, which necessarily involves attentional processing. This proposed multifactorial nature of the VR assessment is therefore, another aspect which suggests that it should have a high degree of ecological validity.

1.8 AIMS OF THE PRESENT STUDY

1.8.1 Primary Questions

The study aims to address four primary research questions as follows:-

1) Is the VR assessment valid as a measure of memory?

Do VR results correlate significantly with other validated measures of memory?
Do VR results correlate significantly with the objective memory questionnaire scores?

2) Is the VR assessment valid as a measure of attention?

Do VR results correlate significantly with the other measures of attention?

3) How valid is the VR assessment compared with ecologically valid measures?

Are the correlations significantly different?

4)What are the cognitive components of VR task performance?

Is the VR assessment more a measure of memory or attention?
That is: To what extent do memory and attention contribute to the cognitive processing in this task?

1.8.2 Secondary Questions

The present study also aims to answer the following questions:

1)Did the amount of exploration carried out within the virtual world relate to the VR task performance?

2)How did 'time taken' to complete the task relate to the amount of information actually recalled?

3) How did the number of errors made in the VR tasks relate to the number of errors made in the standard memory assessments?

4) How did individuals with brain injury react to the VR assessment compared with other tests?

1.9 HYPOTHESES

Relation Between VR Performance and Standard Tests of Memory

A: Scores on the VR memory tasks (free recall and recognition) will correlate positively and significantly with the scores on the standard memory assessments.

B:Correlations between VR task performance (free recall and recognition) and standard tests of verbal memory will be larger than those between the VR memory performance and standard tests of visual memory.

Relation Between VR Performance and Standard Tests of Attention

C: Scores on the VR tasks (free recall and recognition) will correlate significantly with scores on the tests of attention. As many of the attention tests are timed, scores on the VR tasks will correlate **negatively** and significantly with these subtests. That is; the faster the subjects are on timed attention tests, the more effective they will be in the VR tasks.

D: Correlations between the VR tasks and the subtests of sustained and divided attention will be larger than the correlations between the VR tasks and the other attention subtests.

Ecological Validity of the VR assessment compared with standard memory measures

E: The correlations between VR task performance and the ecologically valid memory measures will be significantly greater than the correlations between the standard memory measures and the ecologically valid measures.

The components of the VR task performance

F: Performance on the attention and memory measures will account for separate proportions of the variance in VR memory task performance.

G: The proportion of variance accounted for by standard memory measures will be greater than the proportion accounted for by standard attention measures.

2 : METHOD

2.1 THE VR ASSESSMENT

2.1.1.The VR Tasks

This study involves the use of Superscape Virtual Reality software (Superscape VR plc, 1995) to create a virtual world of four rooms, presented on a standard computer screen. The computer programme gives a 3-D simulation whereby subjects can move in any direction on a horizontal plane, with corresponding shifts in scale and perspective. Twenty five objects from the superscape library are presented within the rooms. The software has been loaned by Professor F.D. Rose, Department of Psychology, University of East London.

Each subject was given a practice run on the VR assessment as a means of familiarising themselves with the task. This involved the use of a joystick to negotiate their way through the four rooms which are empty for the purposes of the practice run. They then enter the same virtual environment, the only difference being that the objects are present. They negotiate their way round the virtual environment as before, but are asked to remember the objects as they go. The first memory component consists of free recall whereby, on completion of travelling through the rooms, the subjects are required to name as many of the objects as possible. This is an explicit memory task in that subjects are told prior to entering the virtual rooms, that they are to remember as many of the objects as possible. The second memory task consists of a recognition task whereby subjects are shown 50 picture cards, one at a time, and asked whether they recognise the object as having been within the virtual rooms. The recognition task was carried out immediately after completion of the free recall task. A standard script was used to describe the procedure to each subject **(see appendix 1).**

2.1.2 Pilot Study

A small pilot study was carried out to determine the speed settings of the joystick. The pilot study involved ten in-patients who had recently suffered some form of neurological damage. The patients were selected at random to be a representative sample of the inpatient population. The patients completed the VR free recall task as described above. The picture cards were not available to the researcher at this point however, so a verbal recognition list was used instead. The joystick settings were altered to enable the subjects to negotiate their way round the virtual rooms with maximum ease. The speed settings on the joystick were set at number 1 (the lowest setting) for forward and backward movement, and were set at number 2 (second lowest setting) for rotational movement, that is, moving around to the right or the left while stationary.

Eight out of the ten individuals in the pilot study required some assistance in using the joystick to negotiate their way through the virtual rooms, particularly concerning movement through the doorways between the rooms. The main concern about this, was that it would have implications for the subjects' performances on the VR tasks. Although it was necessary to help 8 of the subjects, this may have served as a distractor, thus increasing task difficulty when individuals were required to recall information. The VR programme had initially been designed as if the subjects was moving around the rooms while sitting in a wheelchair. The width of the subjects within the virtual environment, was therefore wider than if the subjects had simply been walking. The VR programme was therefore adjusted to make the width of the subject within the virtual world as narrow as possible. This meant that subjects were then able to move through the virtual rooms with greater ease, and without the help of the researcher. The model of joystick used was Interact PC Mission, SV 200.

2.1.3 The Virtual Environment

The virtual environment consists of four rooms with between 5 and 8 objects in each. **Table 2.1** outlines the layout of the virtual rooms. **Table 2.2** outlines the distractor objects that were presented in the VR recognition task.

Appendix 2 shows the pitures that were used in the recognition task.

table 2.1 layout of the objects within the virtual rooms and corresponding object number

Room number	type of room	objects within the room	object number as presented in recognition task
1	bedroom	bed	18
		round table	48
		calculator	22
		camera	24
		clock	26
2	music room	table	34
		film projector	2
		desk/shelves	13
		3 plaques on wall	17
		piano	39
		stool	46
3	living room	TV on stand	6
		painting	10
		plant	11
		coffee table	27
		wine glass	30
		wine bottle	49
		book	21
		green sofa	43
4	kitchen	toy car	5
		washing machine/tumble drier	8
		kitchen units	32
		hob	35
		oven	37
		sink	42

table 2.2 distractor objects presented in recognition task

picture presented in recognition task - not actually present within virtual the environment	object number as presented in recognition task
toy aeroplane	1
paint brush	3
hammer	4
motor cycle helmet	7
toilet	9
iron	12
dust pan	14
umbrella	15
toy bus	16
flowers	19
watering can	20
spectacles	23
waste paper bin	25
fountain pen	28
white chair	29
filing cabinet	31
pink sofa	33
candle	36
ash tray	38
binoculars	40
key	41
audio tape	44
lamp	45
telephone	47
tape reels	50

2.2 MEMORY ASSESSMENT MEASURES USED IN THIS STUDY

2.2.1 Standard clinical memory tests : List Learning and Design Learning

The Adult Memory and Information Processing Battery (Coughlan and Hollows, 1985) involves a **List Learning** test similar to the more widely used Auditory Verbal Learning Test (Rey, 1966). A list of 15 words is read to the subject on 5 consecutive occasions with a recall trial in between each one. A second list is then read out once and the subject is requested to recall as much as possible from this distraction list. The final trial involves delayed recall of the first list. This is a test of memory for verbally presented information. It measures the immediate memory span, provides a learning curve and offers information about any learning strategies being used. List learning also elicits the individual's susceptibility to interference and tendencies to confusion and confabulation. It measures both short term and longer term retention following distraction and allows for comparison between retrieval efficiency and learning.

Design Learning is another subtest from the Adult Memory and Information Processing Battery (Coughlan and Hollows, 1985). This is a visual analogue of the list learning subtest. An abstract design consisting of 9 lines is shown to the subject for a period of 10 seconds and he/she is then requested to reproduce the design. This is repeated over 5 trials and a distractor design is then shown once, for 10 seconds. The final trial involves delayed recall of the first design. As with list learning, this test measures immediate memory span, provides a learning curve and tendencies to confusion and confabulation. It also measures short term and longer term retention and allows for comparison between retrieval efficiency and learning.

Validity of the AMIPB subtests

The AMIPB has not been formally validated against other memory assessments. Correlations between the different memory subtests within the assessment suggest however that the subtests are tapping into different aspects of memory functioning.

Test-Retest Reliability

30 normal subjects between the ages of 24 - 61, were tested at intervals between 1 and 6 days. Pearson correlation coefficients were calculated giving significant results. Practice effects were found to be minimal.

The verbal learning and visual learning subtests of the AMIPB were chosen as they are widely used within the Brain Injury Rehabilitation Unit where the research was carried out. These subtests were also thought to be appropriate assessment measures to use as they are parallel forms of assessment, with similar procedures, in the verbal and visual modalities.

2.2.2 Ecologically valid memory test - The Rivermead Behavioural Memory Test

Wilson et al (1991) criticise test batteries used in the assessment of memory functioning for being too focussed on the acquisition and retention of experimental material. Wilson et al (1985) therefore designed a new battery for memory assessment that has ecological validity. They report that "this test provides more information than the usual standardised test as it is assessing skills necessary for adequate functioning in normal life rather than performance on experimental material." (Wilson et al, 1985, p.3) The test attempts to bridge the gap between laboratory based measures of memory and assessments obtained by observation and questionnaire. The test aims to provide analogues of everyday situations which patients with acquired brain damage often find difficult. The items require the individuals either to remember to carry out some everyday task, or to retain the type of information needed for adequate everyday functioning.

The Rivermead Behavioural Memory Test involves 11 items as follows:-

Subtest 1 :- Remembering a name. The subject is shown a photograph and told the name of the person. He/she, is asked to remember the name and is questioned about it later.

Subtest 2:- Remembering a hidden belonging. A personal possession is borrowed from the subject and hidden. The subject is requested to ask for the object at the end of the session and to remember where it is hidden.

Subtest 3:- Remembering an appointment. The alarm is set for 20 minutes time and the subject is told to ask a particular question when the alarm rings eg. "When is my next appointment?"

Subtest 4:- Picture Recognition. Line drawings of 10 common objects are shown, one at a time, for 5 seconds each. The subject is required to name each picture and after a filled delay, to select the original 10 from a set of 20.

Subtest 5a and 5b:- Prose Recall The subject is asked to listen to a short passage of prose being read out. The subject is then required to recall as much as possible. The subject is later given a delayed recall trial.

Subtest 6:- Face Recognition The subject is shown pictures of 5 faces one at a time. After a filled delay the subject is asked to select the original 5 from a set of 10.

Subtests 7a and 7b:-Remembering a short route. The researcher traces a short route round the room. The subjects is asked to walk round the room to replicate the route. There is a delayed recall trial of the route later in the testing session.

Subtest 8a and 8b:- Remembering to deliver a message. This test is incorporated into subtests 7a and 7b. Prior to tracing the route on both the immediate and delayed recall trials, the subject is required to pick up an envelope and then 'deliver' it while tracing the route, ie. to place it on the table.

Subtest 9:- Orientation and Date. The subject is asked 10 orientation questions such as; What year is it now? What month is it? etc. The question regarding date is scored seperately from the other orientation questions because of a relatively low correlation between this and the other orientation questions in the pilot study.

Prorated scores on the RBMT in the current study.

Five of the subjects who took part in this study were unable to walk or to manoeuvre independently in their wheel chairs. It was necessary therefore to omit subtests 7a and 7b (remembering a short route) and subtests 8a and 8b (remembering to deliver a message) when assessing these subjects. The RBMT scores used in the study depended upon completion of all 9 subtests, or at least to have a score for each subtest. The scores for these five individuals were therefore prorated. This was done by calculating the actual proportion achieved by the subject, of the full possible score, from the subtests that had been completed. This proportion was then adjusted to account for the missed subtests. So, for example, an individual who had achieved 10 out of a possible 16 points for the subtests completed, had achieved 62.5% of the possible score. He/she would therefore be credited with 15 out of a possible 24, as if all subtests had been completed. The proportion correct in this latter instance is 62.5%, the same as the actual proportion achieved. In some instances the calculations did not work to give exactly the same proprtional score, and it was necessary to take the *closest* adjusted proportion.

Validation study of the RBMT

176 brain injured patients were tested at the Rivermead Rehabilitation Centre; 113 men and 63 women. The age range was 14 - 69 with a mean of 44.4. The sample consisted of individuals with various types brain injury including traumatic brain injury, left cerebrovascular accidents (CVAs), right CVAs, subarachnoid haemmorrage, carbon monoxide poisoning, post operative patients and patients with multiple sclerosis.

118 control subjects were tested with an age range of 16 - 69 with a mean age of 41.17. The purpose of the control group was to establish the limits of normal performance on the test and to determine cut-off points for individual components. For each subtest, two scores were produced; a simple pass/fail screening score and a standardised profile score ranging in each case from 0-2. The distribution of scores from patients and controls, on each subtest, was used in order to set cutoff points that maximised the discrimination between the two. Standardisation of the profile score was necessary as the raw scores vary from one test to another. The resultant scores are the screening score ranging from 0-12, and the standardised profile score ranging from 0-24.

Reliability

Inter-rater reliability was established by having 40 subjects scored separately but simultaneously by two raters. There was 100% agreement between the raters for both scoring procedures.

Parallel form reliability was determined by giving two versions of the test to 118 patients. Highly significant correlations were obtained between all combinations of tests given, that is concerning the 4 parallel versions A, B, C and D.

Validity

Comparison or scores on the RBMT between patients and controls.

One crude measure of validity concerns the logical proposal that brain injured patients will have significantly lower scores on the RBMT than controls. The RBMT validation study gives clear evidence that the patients have substantially lower scores than the controls.

Correlations of RBMT scores with scores on standard memory assessments.

The tests used were as follows:

Warrington (1984) Recognition Memory Test for Words and Faces

Digit Span

Spatial Span using the corsi block technique

The paired associate learning subtest from the Randt (Brown and Osborne 1980)

All of the correlations were significant for both the screening scores and the profile scores of the RBMT.

Correlations of RBMT scores with therapists observations of memory lapses

A memory failures checklist was used for this part of the study. The checklist, which asked whether a memory failure had occurred in each of 19 areas (See **appendix 3**) was adapted from one designed by Sunderland, Harris and Baddeley (1983).

A mean of 35 hours of observation per patient was carried out (range 16-55 hours). The correlation between RBMT performance and number of memory lapses reported was -0.71 for the screening score and -0.75 for the standardised profile score ($p=<0.001$ in each case).

2.3 ATTENTION ASSESSMENT MEASURES USED IN THIS STUDY

2.3.1 Standard clinical test of attention -The Trail Making Test

This was originally part of the Army Individual Test Battery (1944). It is commonly used as a test of complex visual scanning with a motor component with motor speed and agility making a strong contribution to success. Part A involves joining letters on a page in the correct order. Part B involves joining numbers and letters in the correct order, alternating between the two, that is, 1 A 2 B 3 C and so on.

When the number of seconds to complete part A is relatively much less than part B, the individual probably has difficulties in complex, double or multiple, conceptual tracking. Slow performances at any age on both A and B, are indicative of brain damage, but in themselves, do not clarify whether the difficulties are due to motor slowing, incoordination, poor visual scanning, poor motivation or conceptual confusion (Lezak, 1995).

Although Trails B has been found to have predicitve validity in relation to driving ability, it is generally not used for this purpose. It is widely used as a standard clinical test of attention.

2.3.2 Ecologically valid test of attention - The Test of Everyday Attention (TEA)

Robertson et al state that "there are several independent attention systems in the human brain serving different functions in everyday behaviour." (Robertson et al, 1994, p.4) The TEA has been designed to look at the main aspects of attention relating them directly to realistic everyday activities. Some preliminary validation data are given in the test manual, but other studies are yet to be completed. Robertson et al suggest that "the TEA will be of considerable clinical use not only in identifying problems that have so far not been assessable, but also in providing measures that predict recovery of function and daily life function over time following brain damage." (Robertson et al, 1994, p.4).

This test battery incorporates 8 subtests which involve four factors of attention as follows:-

Factor 1:- Visual selective attention and speed. This incorporates Lezak's components of Focussed/selective attention and Activity Rate.

Subtest 1:- Map Search - Subjects have to search for symbols on a map (eg. a knife and fork symbol representing restaurants), and circle them with a pen. Map 1 is the number of symbols circled within one minute. Map 2 is the number of symbols circled in two minutes

Subtest 6:- Telephone Search - Subjects look for particular symbols while searching through pages in a simulated telephone directory. Time taken to reach the bottom of the 'telephone page' is recorded.

Factor 2:- Attentional Switching. This corresponds with Lezak's Alternating Attention.

Subtest 4:- Visual Elevator - Subjects have to count up and down as they follow a series of visually presented 'floors' in the elevator. They are required to count forwards or backwards depending on arrows placed intermittently between the pictures. The reversal task is a measure of attentional switching and hence of cognitive flexibility.

Factor 3:- Sustained attention, corresponding with Lezak's Sustained Attention/Vigilance.

Subtest 2:- Elevator Counting - This subtest is based on the procedure devised by Wilkins et al (1987) that was validated as a measure of right frontal lobe based sustained attention. The version used in the TEA is a variation of Wilkins' procedure. Subjects are asked to pretend they are in an elevator whose floor indicator is not working, and listen to tones presented on audio-tape to work out which floor they are on.

Subtest 7:- Telephone Search While Counting - The subject must again search in the telephone directory while simultaneously counting strings of tones presented on audio-tape.

Subtest 8:- Lottery - Subjects have to listen for their winning number which, they have been told, ends in '55'. They must listen to a 10 minute series of audio-tape-presented numbers of the form 'BC143', 'LD967', and so on. The task is to write down the two letters preceding all the numbers ending in 55, of which there are 10.

Factor 4:- Auditory-verbal working memory. This corresponds with Lezak's Immediate Span of Attention.

Subtest 3:- Elevator Task With Distraction - Subjects have to count the low tones in the pretend elevator (presented on audio tape) while ignoring the high tones.

Subtest 5:- Elevator Task With Reversal - This subtest is the same as the visual elevator subtest except that it is presented at a fixed speed on audio-tape.

Two of the subtests outlined above were omitted, namely, subtest 8 (Lottery) and subtest 5 (Elevator Task with Reversal). These omissions were made partly due to time constraints but also because some of the inpatients had found these tasks too demanding. In terms of maintaining the morale of the individuals involved, it was decided that it would be detrimental to try these subtests if the individuals were likely to fail. The remaining six subtests were completed by the majority of subjects. An important point here, is that each of the four attention factors was represented by at least one subtest.

Unlike the scoring procedure in the RBMT, the subtest scores are of greatest importance when looked at individually and are therefore not summed to give an overall 'attention score'. For this reason, the procedure of omitting two subtests in the current study was thought to be justifiable.

Another important point is that divided attention is hypothesised to be pertinent within the VR tasks as the individual must carry out the memory task while also carrying out the motor task. The Test of Everyday Attention however does not have a specific measure of divided attention. Telephone Search While Counting was designed by Robertson et al (1994) to be a test of divided attention, but results of the factor analysis indicate that this subtest loads onto the Sustained Attention factor. Nevertheless, Robertson et al state that this subtest is "sensitive to the ability to handle the complex demands of everyday life - for instance, holding a conversation with one's children at the same time as trying to prepare breakfast, or writing notes for a telephone message while simultaneously speaking to the person leaving the message." (Robertson et al, 1994, p.11) This subtest therefore is the best measure of divided attention to hand, but its limitations for this purpose must be noted.

Validation of the Test of Everyday Attention

154 normal volunteers were tested. The age range was 18 - 80, and the age bands were 18-34, 35-49, 50-64 and 65-80.

Reliability

118 subjects from the normal sample and 74 subjects from a unilateral stroke sample were tested at one week intervals using parallel versions A and B of the test. In additon test-retest reliability figures were given for a subsample of the normal sample who were given Parallel version C one week after completeing test B. All correlations were highly significant except for the 'dual task decrement' in the telephone search while counting subtest. The dual task

decrement is calculated by subtracting the time taken in subtest 6 (telephone search) from the time taken in subtest 7 (telephone search while counting). It therefore represents the extra time needed by the individual to carry out the dual task (searching and counting) rather than the searching task alone. Robertson et al (1994) suggest that the lack of significance here, may be due to the large learning effects which take place from one version to another. They propose however that the measure is likely to be extremely valuable in clinical work as it is highly sensitive to brain damage.

2.4 MEMORY FAILURES CHECKLIST

Memory failures checklists were completed for each subject as a means of quantifying memory failures in everyday situations. Wilson et al (1989) used a memory failures checklist as part of their validation study for the Rivermead Behavioural Memory Test. The same checklist was used in this study **(see appendix 3).** For the purposes of this study, completion of the checklists requires observation of the subjects over half hour intervals. The objective rater then has to tick any memory failures that have occurred for that individual within the half hour period. The inpatient memory failure ratings were completed by members of staff, one in each of the allied professions, that is; nursing, speech and language therapy, occupational therapy and physiotherapy. The half hour time preiod was decided upon as most of the therapy sessions, with inpatients, lasted for approximately this length of time. The same memory failure ratings were completed for outpatients, but by carers/family members. Carers /family members were asked to complete four of the questionaires, in relation to four separate half hour intervals, to match the procedure carried out for inpatients. The memory failure scores reported in the table of raw scores **(Appendix 4)** represent the average number of memory failures for each subject in one half hour interval.

Unfortunately, because the nursing staff do not work with patients on a sessional basis of half an hour (approximately) at a time, their ratings were representative of a more subjective response, rather than being based on observation of definite memory failures. It was decided therefore, not to use the nurses' memory failure ratings.

2.5 INCLUSION/EXCLUSION CRITERIA FOR THE STUDY

Potential subjects were excluded from the study in relation to the following criteria; history of alcohol or drug abuse, premorbid learning disability or psychiatric disorder, visual impairment, hearing impairment, age at time of brain injury - below 16 or above 65 years of age , motor control problems preventing ease of use of the joystick.

These criteria were adhered to as much as possible. For many of the outpatients however, it was not possible to determine from case notes whether or not the individuals did meet the selection criteria completely. Some outpatients who did not entirely meet the selection criteria, were therefore included in the study. One subject for example had a hearing impairment which meant that he was unable to differentiate between tones on the audio tape used in the Test of Everyday Attention. The tests involving the audio tape therefore had to be ommitted. Similarly, one subject with poor fine motor control, was unable to hold a pen or pencil and the written/drawn tests were therefore ommitted. Several patients were able to hold a pen/pencil but due to a residual degree of hemiparesis, were slowed down. In such cases therefore the timed written tests were omitted. These subtest omissions obviously result in an incomplete data set.

2.6 SUBJECTS

43 subjects were assessed using the measures described above; twenty four males and nineteen females. All of the subjects had experienced some form of neurological insult within the past three and a half years. Nine of the subjects were inpatients in the Scottish Brain Injury Rehabilitation Unit at the time of testing. The remaining 34 subjects had been inpatients in this unit within the past 3 and a half years. The subjects in the latter group fell into three categories regarding cognitive deficits:

1) Those who were currently being seen by neuropsychologists connected to the unit, due to ongoing cognitive difficulties.
2) Those who reported cognitive deficits (primarily concerning memory) but who were managing to compensate effectively and did not require intervention.
3) Those who reported that they were not experiencing any cognitive difficulties.

Types of neurological insult within the sample were traumatic brain injury (both penetrating and non penetrating), cerebrovascular accidents (both left and right hemispheres), subarachnoid haemorrhage, anoxia, degenerative disease and damage relating to the surgical removal of tumours. The age range of the sample was from 19 to 64 years. Time since injury varied from 5 weeks to 3 years 5 months. None of the subjects however, had experienced neurological insult prior to the age of 18.

3 : RESULTS

3.1 EXPLORATORY DATA ANALYSIS

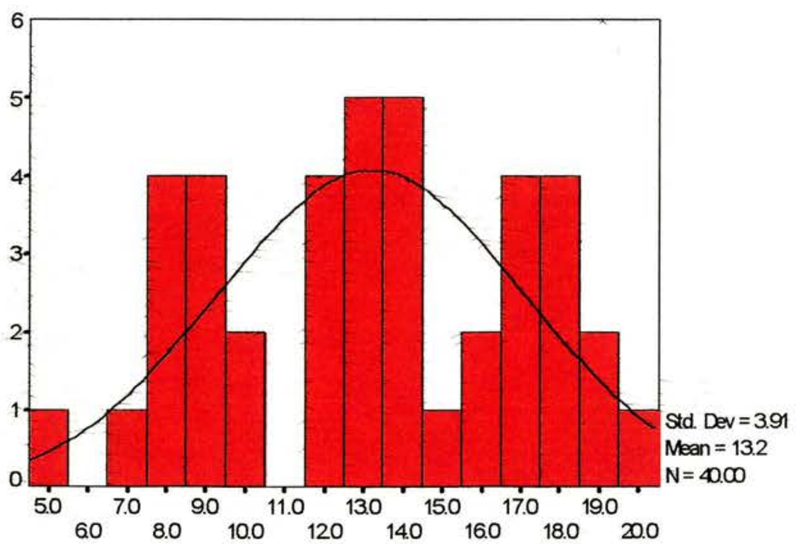
Exploratory data analysis was carried out for two main reasons; firstly, to determine whether the main assessments carried out had a normal distribution and secondly, to ascertain whether there are any outliers within the data.

3.1.1 Normal Distribution

The issue of normal distribution is important in the present study because correlational methods are being used, which assume a bivariate normal distribution. Histograms were computed therefore, concerning the most important assessment measures in the study namely VR free recall, VR recognition and the Rivermead Behavioural Memory Test. **(See diagrams 1, 2,3 and 4.)**

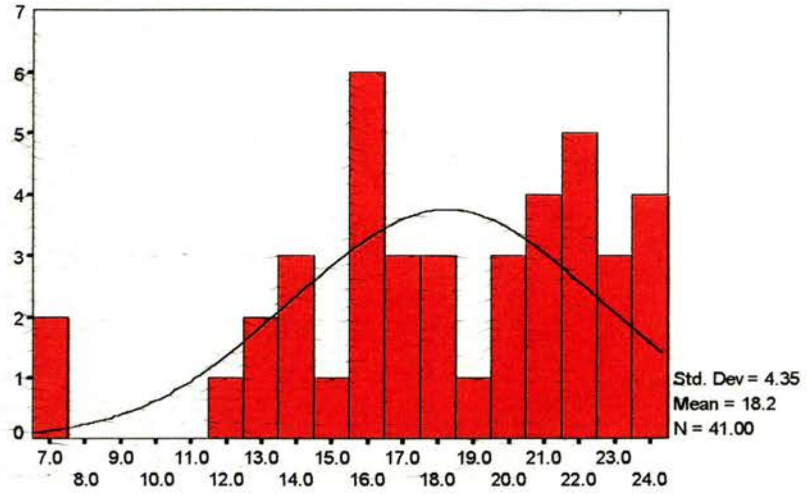
The Y axes on diagrams 1, 2, 3 and 4 illustrate the number of individuals gaining specific scores on the assessment measures.

Diagram 1: Histogram of scores on the VR free recall task



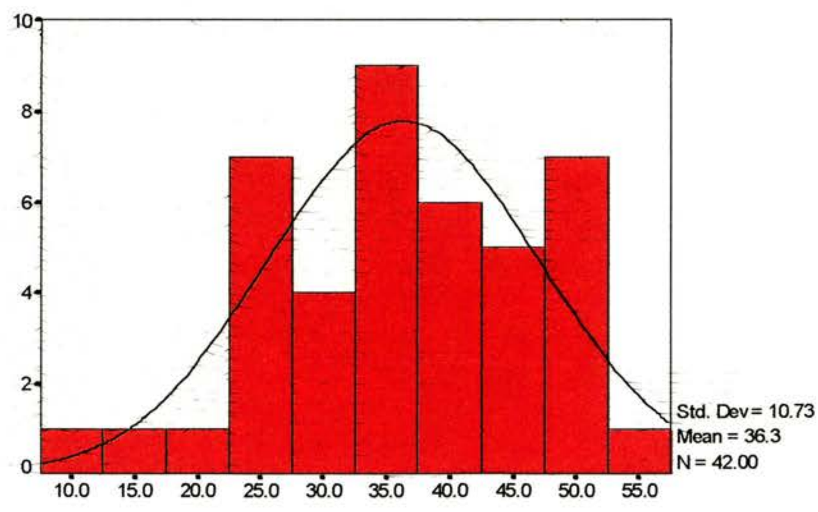
Scores obtained in the VR free recall task,

Diagram 2: Histogram of scores on the VR recognition task



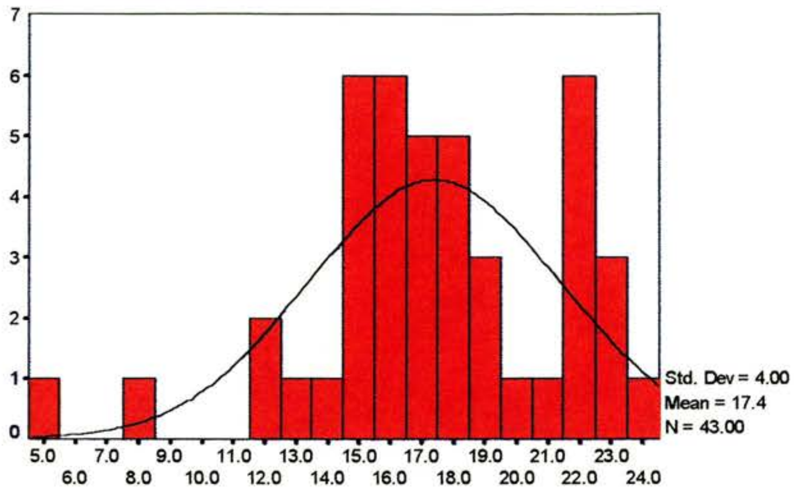
Scores obtained on the VR recognition task

Diagram 3: Histogram of scores on list total - the total number of words recalled over 5 trials.



Scores obtained on list total

Diagram 4: Histogarm of scores on the Rivermead Behavioural Memory Test.



Scores obtained on the RBMT

3.1.2. Outliers

Scatterplots of the main relationships within the study were computed to determine whether any outliers would have a significant effect on the results. **(See diagrams 5,6,7 and 8.)**

No outliers were present.

Diagram 5: Scatterplot of scores on VR free recall and list total.

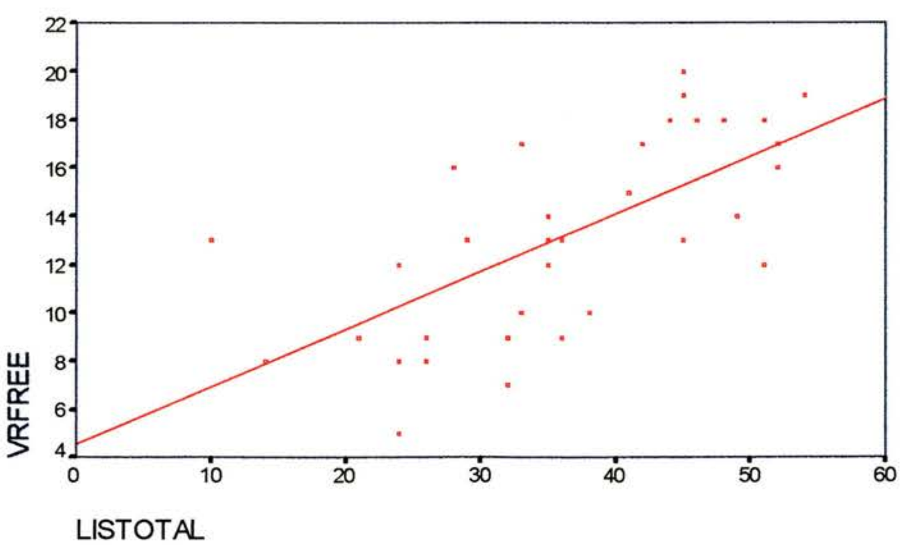


Diagram 6: Scatterplot of scores on VR free recall and the RBMT

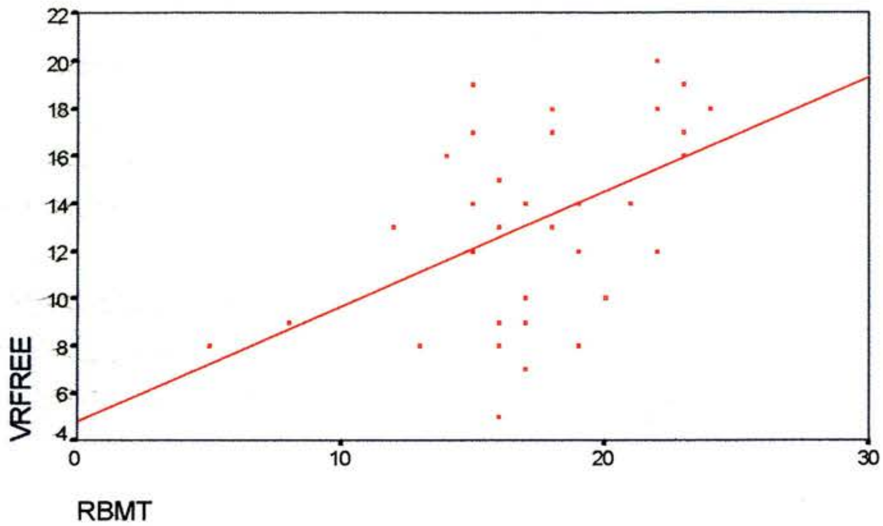


Diagram 7: Scatterplot of scores on VR recognition and list total

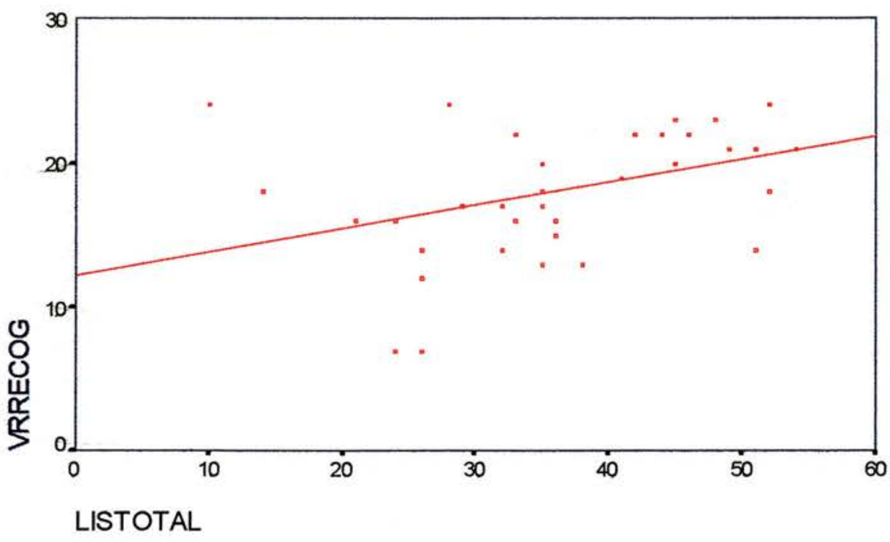
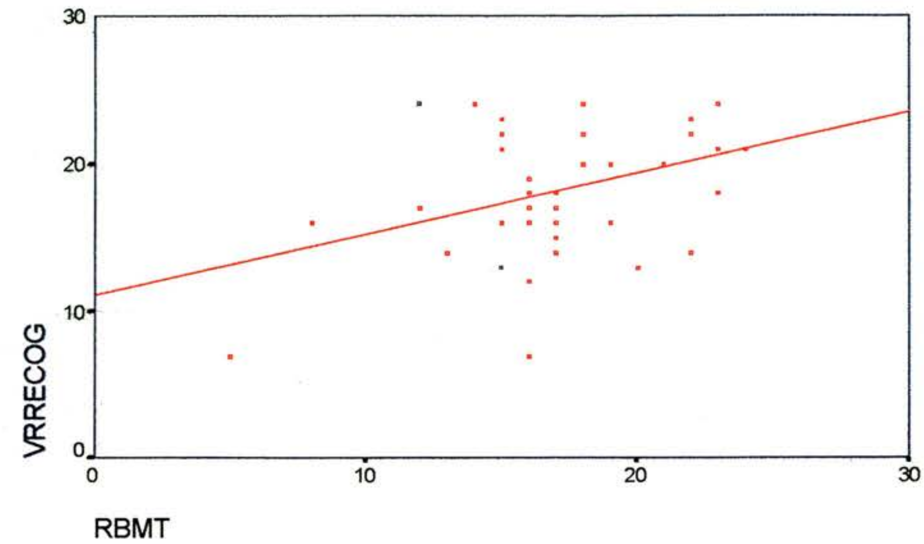


Diagram 8: Scatterplot of scores on VR recognition and the RBMT



3.2 IS THE VR ASSESSMENT VALID AS A MEASURE OF MEMORY?

Hypothesis A states that scores on the VR memory tasks will correlate positively and significantly with the scores on standard memory assessments. This concerns the concurrent validity of the VR tasks as measures of memory functioning.

Hypothesis B states that the correlations between VR task performance and standard tests of verbal memory will be larger than those between the VR task performance and standard tests of visual memory.

In order to test these hypotheses, one tailed bivariate correlations were computed. Scores on both the VR free recall condition and the VR recognition condition correlate significantly with the scores on all the memory assessments. **(see table 1)** Hypothesis A has therefore been substantiated.

table 1 : bivariate correlations between the VR tasks and memory assessments

	VR recog-nition	check-list	RBMT	design total	design 6	list total	list 6	list recog-nition
VR free recall	**0.8177 (40) p<0.001**	**-0.5364 (35) p<0.001**	**0.4856 (40) p=0.001**	**0.4408 (39) p=0.002**	**0.5458 (39) p<0.001**	**0.6714 (40) p<0.001**	**0.5352 (40) p<0.001**	**0.4958 (40) p=0.001**
VR recog-nition	-----	**-0.3949 (35) p=0.009**	**0.3745 (41) p=0.008**	**0.3277 (40) p=0.020**	**0.4382 (40) p=0.002**	**0.4110 (40) p=0.004**	**0.3226 (40) p=0.021**	**0.3348 (40) p=0.017**
check-list	-----	-----	**-0.4324 (35) p=0.005**	**-0.5372 (34) p=0.001**	**-0.4878 (34) p=0.002**	**-0.5185 (35) p=0.001**	**-0.4416 (35) p=0.004**	-0.2770 (35) p=0.054
RBMT	-----	-----	-----	**0.2942 (42) p=0.029**	**0.3464 (42) p=0.012**	**0.5566 (42) p<0.001**	**0.4761 (42) p=0.001**	**0.3297 (42) p=0.016**

(significant correlations are printed in bold.)

Table 2 : reproduction of section from table 1, showing bivariate correlations between the VR tasks and the visual and verbal memory assessments.

	design total	design 6	list total	list 6	list recog-nition
VR free recall	**0.4408 (39) p=0.002**	**0.5458 (39) p<0.001**	**0.6714 (40) p<0.001**	**0.5352 (40) p<0.001**	**0.4958 (40) p=0.001**
VR recog-nition	**0.3277 (40) p=0.020**	**0.4382 (40) p=0.002**	**0.4110 (40) p=0.004**	**0.3226 (40) p=0.021**	**0.3348 (40) p=0.017**

(significant correlations are printed in bold.)

As noted earlier, the correlations between the VR tasks and the visual and verbal memory tasks are all significant. The correlations between the VR free recall and the verbal memory subtests seem to be higher overall than the correlations between the VR tasks and the visual memory subtests. (This refers to the middle row of table 2.) Most pertinently, the correlation between list total and VR free recall is greater than the correlation between design total and VR free recall.

The correlations between VR recognition and the visual memory subtests appear to be equal to the correlations between VR recognition and the verbal memory subtests.

Hypothesis B therefore is only partially substantiated.

3.3 IS THE VR ASSESSMENT VALID AS A MEASURE OF ATTENTION?

Hypothesis C states that scores on the VR tasks (free recall and recognition) will correlate significantly with scores on the tests of attention. As many of the attention tests are timed, scores on the VR tasks will correlate **negatively** and significantly with these subtests. That is; the faster the subjects are on timed attention tests, the more effective they will be in the VR tasks.

Hypothesis D states that correlations between the VR tasks and the attention subtests concerning sustained and divided attention will be larger than the correlations between the VR tasks and the other attention subtests.

One tailed bivariate correlations were computed to test these hypotheses. As can be seen from **table 3** results on the VR free recall task and the VR recognition task correlate differently with the various attention subtests and will therefore be discussed separately.

table 3 : bivariate correlations between the VR tasks and attention assessments

	VR free recall	VR recognition
Trails A	**- 0.3637 (36) p=0.015**	-0.2263 (36) p=0.092
Trails B	**- 0.2890 (36) p=0.044**	-0.1459 (36) p=0.198
Map 1	**0.5584 (34) p<0.001**	**0.3821 (35) p=0.012**
Map 2	**0.4831 (34) p=0.002**	**0.3197 (35) p=0.031**
elevator counting	0.1564 (36) p=0.181	0.1900 (37) p=0.130
elevator counting with distraction	0.1137 (35) p=0.258	0.0208 (36) p=0.452
visual elevator accuracy	**0.3494 (37) p=0.017**	**0.5209 (37) p<0.001**
visual elevator time	**- 0.5915 (37) p<0.001**	**- 0.5871 (37) p<0.001**
telephone search	**- 0.4972 (33) p=0.002**	**- 0.4809 (34) p=0.002**
telephone search while counting	-0.1602 (32) p=0.191	0.1099 (32) p=0.275

(significant correlations are printed in bold.)

<u>**Correlations between VR recognition and the attention subtests**</u>

VR recognition performance correlates significantly with the following attention subtest scores; Map 1, Map 2, visual elevator accuracy, visual elevator time and telephone search. It does not however correlate significantly with Trails A, Trails B, elevator counting, elevator counting with distraction or telephone search while counting. As with VR free recall, VR recognition correlates negatively with the attention tests that have timed scores.

Hypothesis C has therefore only been partially substantiated as the VR tasks only correlate significantly with *some* of the attention subtests. Hypothesis D must be rejected completely as correlations between the VR tasks and the attention subtests concerning sustained and divided attention are *not* greater then the correlations between the VR tasks and the other attention subtests. Most pertinently the correlations between the VR tasks and the subtest concerning divided attention (telephone search while counting) are not significant.

3.4. TESTING THE DIFFERENCE BETWEEN TWO NON- INDEPENDENT CORRELATION COEFFICIENTS

Hypothesis E states that the correlations between VR task performance and the ecologically valid memory measures will be significantly greater than the correlations between the standard memory measures and the ecologically valid measures.

In order to test this hypothesis it was necessary to determine whether the VR/ecologically valid test correlations were greater than the standard/ecologically valid measures. The relevant correlations are presented in **table 1**. **Table 4** presents a summary of the comparisons being made, in relation to hypothesis E.

table 4 : comparison of correlations in relation to hypothesis E

Correlations between VR tasks and ecologiclly valid measures.	Symbol indicating whether the correlation on the left is greater than the correlation on the right.	Correlations between standard measures and ecologically valid measures.
VR free recall/RBMT	<	list total (trials 1-5)/RBMT
	>	design total (trials 1-5)/RBMT
	>	list 6/RBMT
	>	design 6/RBMT
	>	list recognition/RBMT
VR recognition/RBMT	<	list total (trials 1-5)/RBMT
	>	design total (trials 1-5)/RBMT
	<	list 6/RBMT
	>	design 6/RBMT
	>	list recognition/RBMT
VR free recall/checklist	>	list total (trials 1-5)/checklist
	<	Design total (trials 1-5)/ checklist
	>	list 6 / checklist
	>	design 6 / checklist
	>	list recognition / checklist
VR recognition/checklist	<	list total (trials 1-5)/checklist
	<	Design total (trials 1-5)/ checklist
	<	list 6 / checklist
	<	design 6 / checklist
	>	list recognition / checklist

By referring to **table 4**, it can be seen that some of the correlation comparisons show relationships in the wrong direction. This means that some of the correlations between standard memory subtests and the ecologically valid measures are greater than some of the correlations between the VR tasks and ecologically valid measures. This is in opposition to hypothesis E. Twenty comparisons are made however, twelve of which show relationships in the hypothesised direction. Out of the 10 comparisons concerning VR free recall, 8 are in the predicted direction. Only 4 out of the 10 comparisons concerning VR recognition are in the predicted direction however. This suggests that there is a *trend* for correlations between the VR free recall tasks and ecologically valid measures to be greater than correlations between standard memory meaures and ecologically valid measures.

An alternative way of looking at the results is that 7 out of the 10 relationships concerning the RBMT are in the predicted direction while 5 out of the 10 relationships concerning the memory failures checklist are in the predicted direction. This is not a particularly useful way of reporting the results at the moment, but does raise interesting issues which will be discussed later (see section 4.3.5).

The comparisons which do represent relationships in the hypothesised direction were analysed further to determine whether differences were statistically significant.
The following equation was used, (Howell, 1982):

$$t = \frac{(r_1 - r_2)\sqrt{(N-3)(1+r_3)}}{\sqrt{2(1 - r_1^2 - r_2^2 - r_3^2 + 2r_1 r_2 r_3)}}$$

The first relationship shown in table 4 that is in the hypothesised direction concerns the correlations between VR free recall and the RBMT, and between design total and the RBMT. The following values were therefore put into the equation shown above, to calculate the t value;

r 1 is the correlation between VR free recall and the RBMT.

r 2 is the correlation between design total and the RBMT.

r 3 is the correlation between VR free recall and design total.

The t value obtained was not significant ($p < 0.05$), indicating that VR free recall is not more ecologically valid than design total.

The same equation was used to calculate t values for the remaining 11 relationships, substituting in the appropriate values for r 1, r 2, and r 3 each time. Only one t value was significant at the 5% level, as follows; VR free recall was found to be more ecologically valid than list recognition in relation to the memory failures checklist; $t = 1.73$ ($p=0.05$).

VR free recall was found to be more ecologically valid than list recognition, in relation to the RBMT, at the 10% level; $t = 1.64$.

Despite a trend in the data for correlations between the VR free recall task and the ecologically valid measures to be greater than the correlations between the standard tests and the ecologically valid tests, Hypothesis E must be rejected.

3.5 COGNITIVE COMPONENTS OF THE VR TASK PERFORMANCE

3.5.1 Linear regression and independent variables - the rationale

Hypothesis F states that performance on the attention and memory measures will account for separate proportions of the variance in VR memory task performance. Hypothesis G states that the proportion of variance accounted for by standard memory measures will be greater than the proportion accounted for by standard attention measures. Multiple regression was carried out on the relevant data in order to test these hypotheses. It was then possible to calculate the semi-partial correlation coefficients as a means of determining the exact contribution of each independent variable to the VR task performances.

In order to carry out the regression calculations, it was necessary to determine which factors should be included as the independent variables. This study proposes that the two main factors involved in the cognitive processing in the VR tasks are memory and attention. As discussed in the introduction however, memory and attention are complex, multifactorial components of the overall processing capacities of the human brain.

Independent variables - subcomponents of memory

The memory factor has been subdivided into visual memory and verbal memory, in relation to design learning (total scores in trials 1-5) and list learning (total scores in trials 1-5). The design learning scores are therefore taken as a measure of visual memory while the list learning scores are taken as a measure of verbal memory. Some consideration was given to whether design learning trial 6 and list learning trial 6 may be better measures of visual and verbal memory. As outlined by Coughlan and Hollows (1985) however, the list recall and design recall in trial 6 of each subtest is representative of 'susceptibility to interference', as they require recall of information after distraction. It was decided therefore, that the total scores in trials 1-5 for each subtest, would the the best representatives of visual and verbal memory.

Independent variables - subcomponents of attention

The attention component is divided into four factors as determined by the validation study for the Test of Everyday Attention. As can be seen from table 2 however, some of the attention scores do not correlate significantly with the VR scores. These subtests therefore do not contribute to the variance in the VR tasks. Two attentional factors were therefore eliminated from the regression equation, namely Sustained Attention and Auditory Verbal Working Memory. The subtests representing the remaining two attention factors all correlate significantly with the VR tasks and were therefore kept in the equation, namely Visual Selective Attention And Speed and Attentional Switching. Attentional switching is represented by the the visual elevator task, for which there are two scores; visual elevator accuracy and visual elevator time. Visual selective attention and speed is represented by the map search task and the telephone search task. The "purest' measure was therefore calculated for each factor for inclusion in the regression calculation. This was done by calculating which subtest was least correlated with the subtests from each of the other attention factors. The subtest with the lowest sum was taken as the best representative of each factor respectively. The attention subtests used in the multiple regression calculation therefore, were telephone search (Visual Selective Attention and Speed) and visual elevator accuracy (Attentional switching).

Table 5 summarises which subtests were included in the regression equation and also which factor each subtest represents.

Table 5 : factors, relating to subtest scores, used in the linear regression

Subtest	Factor
design total (trials 1-5) (Adult Memory and Information Processing Battery)	Visual memory
list total (trials 1-5) (Adult Memory and Information Processing Battery)	Verbal memory
Telephone search (Test of Everyday Attention)	Visual Selective Attention and Speed
Visual elevator accuracy (Test of Everyday Attention)	Attentional Switching

Linear regression was carried out with VR free recall as the dependent variable and then with VR recognition as the dependent variable; the independent variables (as tabulated above) were the same for both calculations.

3.5.2 Linear Regression of VR free Recall Scores

As can be seen from **table 6**, visual memory, verbal memory, visual selective attention and speed and attentional switching, together account for 51.5% of the variance in the VR free recall task. The predictor measures are all inter-related to some extent so that only two of them emerge as making significant individual contributions. Visual learning and visual elevator accuracy do not add any significant individual contributions. (sig T == 0.52 and 0.66 respectively.) The semi partial correlations however, show that verbal learning alone accounts for 8.6% of the variance, while visual selective attention and speed accounts for 5% of the variance. 37.9% of the variance therefore, is shared between the four independent variables.

Table 6 : Linear regression : dependent variable = VR Free Recall

$R^2_{ABCD} = 0.51514$ where A = 'design total' representing visual memory
B = 'list total' representing verbal memory
C = 'Telephone search' representing visual selective attention and speed
D = 'visual elevator accuracy' representing attentional switching

Table 6.1 Analysis of Variance

	DF	sum of squares	mean square
Regression	4	252.08541	63.02135
Residual	28	237.26844	8.47387

F = 7.43714 Signif F = 0.0003

Table 6.2 Beta weights and semipartial correlations

	B	**SE B**	**Beta**	**T**	**Sig T**	**semipartial correlation**
design total	0.057968	0.89406	0.118147	0.648	0.5220	0.00728
list total	**0.166083**	**0.74420**	**0.455640**	**2.232**	**0.0338**	**0.08625**
Telephone search	**-0.487043**	**0.286231**	**-0.270274**	**-1.702**	**0.0999**	**0.05014**
visual elevator accuracy	0.146327	0.327808	0.065116	0.446	0.6588	0.00345
(constant)	6.872111	3.634903		1.891	0.0691	

3.5.3 Linear regression of VR recognition Scores

The results presented in **table 7** show that 42.6% of the variance in the VR recognition task is explained by the four independent variables. Visual and verbal learning do not make significant individual contributions. (Sig T = 0.18 and 0.85 respectively). Visual selective attention and speed emerges as making a significant individual contribution of 8.4% of the variance while attentional switching makes a significant individual contribution of 10.4% of the variance. 23.8% of the variance therefore is shared by the four independent variables.

Table 7 : Linear regression : dependent variable = VR Recognition

$R^2_{ABCD} = 0.42554$ where A = 'design total' representing visual memory
B = 'list total' representing verbal memory
C = 'Telephone Search' representing visual selective attention and speed
D = 'visual elevator accuracy' representing attentional switching

Table 7.1 : Analysis of Variance

	DF	sum of squares	mean square
Regression	4	265.95983	66.48996
Residual	29	359.02798	12.38028

F = 5.37064 Signif F = 0.0023

Table 7.2 : Beta weights and semipartial correlations

	B	SE B	Beta	T	Sig T	semipartial correlation
design total	0.147147	0.106417	0.269489	1.383	0.1773	0.03794
list total	-0.016547	0.088579	-0.040791	-0.187	0.8531	0.00069
Telephone Search	**-0.701309**	**0.340690**	**-0.349707**	**-2.058**	**0.0486**	**0.08393**
visual elevator accuracy	**0.892016**	**0.390177**	**0.356694**	**2.286**	**0.0297**	**0.10353**
(constant)	11.593969	4.327541		2.679	0.0120	

Hypothesis F has therefore only been partially substantiated. Attention and memory factors account for separate proportions of the variance in the VR free recall task but only attention factors make additional independent contributions in the VR recognition task. Hypothesis G has similarly only been partially substantiated. Verbal memory accounts for more of the variance than any of the attention factors in VR free recall, but the memory subtests do not emerge as significant independent predictors in relation to the VR recognition task.

3.6 SECONDARY QUESTIONS

3.6.1.Exploration within the virtual environment and VR task performance

The first secondary question to be addressed is; Did the amount of exploration carried out within the virtual environment relate to VR task performance? VR path length is the actual distance that the individual travelled around the virtual environment, and is therefore a measure of the amount of exploration carried out. Bivariate correlational analysis was carried out as a means of looking at the relationship between VR path length and VR performance. As can be seen from **table 8**, the amount of exploration does not correlate significantly with any of the VR measures.

3.6.2 Relationship between time taken to complete the VR task and VR task performance

The next secondary question to be addressed is; how did 'time taken' to complete the task relate to the amount of information actually recalled? Bivariate correlations were computed to address this question and the results are presented in **table 8**.

table 8 : bivariate correlations between VR path length, VR time and VR memory tasks and errors

	VR path length	VR time
VR free recall	0.0127 (39) p=0.469	0.1491 (39) p=0.183
VR free recall errors	0.0760 (39) p=0.323	-0.0015 (39) p=0.496
VR recognition	-0.0520 (40) p=0.375	0.1284 (40) p=0.215
VR recognition errors	-0.0686 (40) p=0.337	-0.2223 (40) p=0.084

bivariate correlation of
VR path length and VR time
=0.0955
(41)
p=0.276

Time taken to complete the task does not correlate significantly with any of the VR performance measures. The correlation between time taken and the number of errors in the recognition task is approaching significance however. ($r= -0.2223$, $p= 0.084$). This suggests that the more time the individual spends in the virtual environment, the fewer errors he/she will make in the picture recognition task.

3.6.3 VR task errors

Another secondary question posed was; how did the number of errors made in the VR tasks relate to the number of errors made in the standard memory assessments?

Once again, bivariate correlations were computed. **Table 9** summarises these results.

table 9 : bivariate correlations of VR errors and memory assessment errors

	VR free recall errors	VR recognition errors
design errors trials 1-5	0.1880 (39) p=0.126	**0.4174 (40) p=0.004**
design errors trial 6	**0.2982 (39) p=0.033**	**0.5289 (40) p=0.000**
list errors trials 1-5	0.1767 (40) p=0.138	-0.0119 (40) p=0.471
list errors trial 6	0.1920 (40) p=0.118	0.2140 (40) p=0.092
list recognition errors	0.2612 (40) p=0.052	0.0798 (40) p=0.312

(significant correlations are printed in bold.)

Bivariate correlation of
VR free recall errors and
VR recognition errors

=0.4001
(40)
p=0.005

3.6.4 Qualitative analysis of the VR assessment

Overall, the response of subjects to the VR assessment was favourable. They were asked their opinion on completion of the VR free recall and VR recognition tasks. **Table 10** illustrates some of the favourable comments while **table 11** illustrates some of the more negative comments made by subjects.

Table 10 : Favourable comments made regarding the VR assessment

Favourable comments made by subjects regarding the VR assessment
I preferred it to some of the other tests because it felt more like playing a computer game.
It wasn't as threatening as the other tests.
It was more interesting to do.
I quite enjoyed it.
I felt that I had more success on that one.
It was easier to concentrate during that test because it was more interesting.
It felt a bit more realistic than just remembering a list of words.
I enjoyed that one more than some of the other tests.
It was easier to concentrate on that one.

Table 11 : Unfavourable comments made regarding the VR assessment

Unfavourable comments made by subjects regarding the VR assessment
I couldn't concentrate on the different things in the rooms because I was concentrating so much on trying to use the joystick.
I found it difficult to use the joystick.
There was too much to remember.
I kept trying to remember what I'd seen at the beginning and couldn't take in any more in the last 2 rooms.
I've never used a computer before and it's probably too late to start now.
I'm too old to start using computers now.

4 : DISCUSSION

4.1 AIMS OF THE STUDY

As discussed in the introduction, cognitive impairment is commonly reported after all types of neurological insult. Cognitive deficits can have far reaching consequences for individuals coping with the demands of day to day living. In order to maximise patients' abilities after brain damage, it is necessary to plan individual rehabilitation programmes. The neuropsychological assessment is therefore absolutely vital in determining exactly what cognitive deficits are being experienced, prior to planning the individual rehabilitation programmes. Standard neuropsychological assessments have been subject to criticism, mainly due to their lack of ecological validity, that is, they relate poorly to real life situations. Another more ecologically valid form of memory assessment (the Rivermead Behavioural Memory Test) is criticised by the present researcher however, as being too far removed from cognitive models of memory functioning. Andrews et al (1995) suggested that a cognitive assessment carried out within a virtual environment would be particularly realistic while having the benefit of strict control. The main aims of this study therefore, are 1) to determine whether the virtual reality computer programme, used by Andrews et al, is valid as a form of cognitive assessment and 2) to determine the extent to which the VR assessment is ecologically valid. Memory and attention, as two inextricably linked aspects of cognitive functioning, are the focus of the assessments.

4.2 SUMMARY OF MAIN FINDINGS

Seven hypotheses were proposed, only some of which were borne out by the results. The VR assessment was found to have concurrent validity in relation to several other forms of memory assessments, both standard and ecologically valid. It also correlated significantly with objective reports of the subjects' memory failures. In relation to its use as an attention assessment, the VR tasks were found only to correlate significantly with *some* of the subcomponents of attentional functioning. There is a trend in the data suggesting that the VR free recall task is a more ecologically valid assessment of memory functioning than standard memory measures, but this does not hold for the VR recognition task.

4.3 DISCUSSON OF INDIVIDUAL HYPOTHESES

4.3.1 Hypothesis A

Scores on the VR memory tasks will correlate positively and significantly with the scores on standard memory assessments.

This hypothesis was confirmed. The VR tasks both correlate significantly with the standard assessments of verbal and visual memory; namely list learning (list total, list 6 and list recognition) and design learning (design total and design 6). The correlations with VR free recall were higher in each instance than the correlations with VR recognition, suggesting that VR free recall may be a better indicator of memory functioning. One finding here that is rather surprising, is that the correlation between VR free recall and list recognition is *greater* than the correlation between VR recognition and list recognition. It would be reasonable to expect the latter correlation to be greater because both tasks concern the subjects' recognition of stimuli. It must be noted however that the list recognition task involves recognition of words presented in a written format whereby the VR recognition task involves the recognition of objects presented in a pictorial format. It could be argued that these recognition tasks will involve processing in opposite hemispheres of the brain because one is visual and one is verbal, and that the tasks are therefore not likely to correlate as significantly as the VR free recall and List recognition tasks which are both verbal. It is proposed however that the VR recognition task is likely to involve verbal processing rather than visual processing as the subjects are likely to verbalise the name of the object, while negotiating their way through the virtual rooms as a means of aiding the encoding process. This proposal is supported by the fact that the correlation between VR recognition and list learning is greater than the correlation between VR recognition and design learning. That is, the VR recognition task is more similar to the task of verbal memory than to the task of visual memory, indicating that it involves more verbal processing than visual processing.

4.3.2 Hypothesis B

Correlations between VR task performance and standard tests of verbal memory will be larger than those between the VR task performance and standard tests of visual memory.

The largest correlation here is between VR free recall and list total, suggesting that the VR free recall task is more similar to this verbal learning task than any of the other standard visual or verbal memory tasks. In the VR free recall task, subjects are being asked to recall as many objects as possible from the virtual environment whereas in the list learning task, they are asked to recall words from the list over five consecutive trials. These two tasks are different in terms of the stimuli being presented. One obviously involves the visual presentation of information (pictures of objects on the computer screen), while the other involves auditory presentation of information (recitation of the word list). The similarity lies in the mode of recall whereby the subjects are asked, in both tasks, to give verbal feedback of what they can recall. Despite the different types of stimuli being presented, it is more likely that the encoding of the information is verbal in both the VR and the list learning tasks. As the free recall and recognition tasks in the VR assessment are both based on the encoding of exactly the same information, it is assumed that this encoding occurs via verbal processing rather than visual processing.

The correlations between VR recognition and the visual and verbal memory tasks do not vary greatly. This suggests that the VR recognition task relies equally on visual and verbal processing contradicting the hypothesis that both VR tasks rely on verbal memory processing rather than visual memory processing. As will be discussed in section 4.3.6.2, the cognitive processing involved in the VR recognition task is largely to do with attentional processing rather than visual or verbal memory processing.

4.3.3 Hypothesis C

Scores on the VR tasks will correlate significantly with scores on the tests of attention. As many of the attention tests are timed, scores on the VR tasks will correlate *negatively* and significantly with these subtests.

The results are not entirely consistent with this hypothesis.

VR free recall correlates significantly with Trails A and Trails B ($r = -0.36$ and $r = -0.29$ respectively) suggesting that part of the processing in this VR task concerns motor speed and visual tracking. Similarly, the correlations with Map search (Map 1, $r = 0.56$ and Map 2, $r = 0.48$) and telephone search ($r = 0.5$) are indicative of the involvement of visual selective attention and speed. The correlation with visual elevator accuracy (r = 0.35) suggests that attentional switching is an important component in the VR free recall task while the correlation with visual elevator time (r = - 0.59) again suggests the importance of speed. Overall then, the important attentional components of the VR free recall task seems to be speed of information processing, visual tracking, visual selective attention and attentional switching, as well as a possible motor speed component.

Scores on the VR recognition task do not correlate significantly with Trails A and Trails B. This would suggest that the VR recognition task does not rely as much on motor speed and visual tracking as the free recall task.

The VR recognition and free recall tasks correlate significantly with all the other attentional subtests: namely Map search (Map 1, r= 0.38 and Map 2, r=0.32), telephone search (r= - 0.48), visual elevator accuracy (r= 0.52) and visual elevator time (r= -0.59). These data suggest that the VR recognition task also involves; speed of information processing, visual selective attention and attentional switching, as well as a possible motor speed component. The results concerning Trails A and B are therefore inconsistent in that Robertson et al (1995) report that Trails B loads onto their factor of visual selective attention and speed. If all the other visual selective attention and speed subtests correlate significantly with VR recognition, why does Trails B *not*? Also, why should VR free recall correlate significantly with Trails A and B if VR recognition *does not*? This result is unexpected and can not be explained by the researcher.

The VR free recall and recognition scores did not correlate significantly with elevator counting (sustained attention), elevator counting with distraction (auditory verbal working memory) and telephone search while counting (sustained attention). It makes sense that the VR tasks do not rely heavily on auditory verbal working memory as the task itself is not auditory. It is likely that the VR task is partially reliant on working memory in the visual -verbal modalities, rather than the auditory -verbal modalities.

Elevator counting (EC) and telephone search while counting (TSWC) both load onto the same factor (sustained attention) within the factor analysis of the Test of Everyday Attention. (Robertson et al 1995). As mentioned earlier however, telephone search while counting was designed by Robertson et al as a divided attention task. Although not ideal, TSWC is actually the best measure of divided attention within this study. This leads therefore onto Hypothesis D.

4.3.4 Hypothesis D

Correlations between the VR tasks and the subtests of sustained and divided attention will be larger than the correlations between the VR tasks and the other attention subtests.

This hypothesis is proposing quite simply that the VR tasks are likely to be more similar to the sustained and divided attention tasks than to any of the other attention tasks. As outlined above however, the VR tasks do not correlate significantly with the sustained and divided attention subtests, thus contradicting Hypothesis D. This is unexpected in that the VR tasks should involve sustained attention by virtue of the fact that the individuals must attend for the duration of time that it takes them to complete the task. Similarly, because the VR assessment requires the individual to carry out two tasks at once, that is, the memory task and movement through the virtual environment, it was hypothesised that this would necessarily involve divided attention. This will be discussed more fully in section 4.5 in relation to the cognitive components of VR task performance.

4.3.5 Hypothesis E

The correlations between VR task performance and the ecologically valid memory measures will be greater than the correlations between the standard memory measures and the ecologically valid measures.

This hypothesis is only partially substantiated in that there is a *trend* in the data suggesting that VR free recall is more ecologically valid than standard memory assessment measures. VR recognition however, does not appear to have a high degree of ecological validity.

The results regarding hypothesis E were presented in 2 ways (see section 3.4), the latter of which is most useful for the current discussion. In theory, the memory failures checklist is the most ecologically valid way of measuring memory difficulties in day to day living. Only 5 out of the 10 relationships concerning the VR tasks and the checklist were in the hypothesised direction. (4 concerning VR free recall and 1 concerning VR recognition). It is suggested that within the current study, the memory failures checklist does *not* give a very good representation of memory difficulties in real life. This is by virtue of the fact that the memory failure scores in this study are based on a *maximum* of two hours of observation concerning each subject. Some of these scores are actually based on as little as one half - hour period of observation. (This was determined entirely by the number of checklists that were returned to the researcher by the carers/relatives.) This will be discussed in section 4.6.

In relation to the RBMT, seven out of the ten correlations were in the predicted direction, suggesting a trend for the greater ecological validity of the VR assessment compared with standard memory assessments.

4.3.6 Hypotheses F and G

Because these hypotheses are interconnected, it is simpler to discuss them together than separately. The hypotheses are as follows:

Performance on the attention and memory measures will account for separate proportions of the variance in VR memory task performance.

The proportion of variance accounted for by standard memory measures will be greater than the proportion accounted for by the attention measures.

Memory and attention contribute differently to the VR free recall and recognition tasks however. For the purposes of this discussion therefore, VR free recall and VR recognition will be looked at separately.

4.3.6.1 Cognitive components of VR free recall

The results here are somewhat surprising, as verbal memory and visual selective attention and speed are the only two components that make significant independent contributions to the variance in the VR free recall task. Verbal memory (list learning - total recall over trials 1-5) accounts for 8.6% of the variance while visual selective attention and speed (telephone search) accounts for 5% of the variance. Visual memory and attentional switching do not contribute independently to the variance.

It is perhaps unsurprising that visual memory does not contribute independently in the VR task as it has been argued by the current author that the names of objects are likely to be verbalised by subjects as a means of aiding the encoding process. It was apparent while carrying out the VR assessment with some subjects that they did indeed rehearse the names of objects quietly to themselves as they moved through the virtual environment. Other subjects reported on completion of the VR tasks that they had been saying the names of objects to themselves silently, although this was obviously not apparent to the researcher. Another important point here is that design learning, the subtest used as a measure of visual memory, is actually a test of *abstract* visual stimuli whereas the VR task involves memory for concrete visual stimuli (household objects). The abstract pictures in the design learning subtest can not be verbally encoded and are therefore more likely to be processed in the right hemisphere, while concrete designs and verbal stimuli will be processed in the left hemisphere.

It would certainly make sense that speed of information processing would be an important component in the VR tasks as the more efficient an individuals' cognitive processes are, the more he/she would be likely to remember. It is arguable however, whether or not motor speed is likely to be a contributing variable to success in the VR tasks. It could be argued that time taken to move through the virtual environment is the most direct measure of the involvement of motor speed. As will be discussed more fully in section 4.6, the time taken to complete the VR negotiation task does not correlate significantly with the amount of information remembered, either in free recall or recognition.

Visual selective attention would logically be an important component of the VR free recall task, as the individuals must selectively attend to the objects presented in the virtual environment for encoding of that object to occur within the memory system of the brain. The individuals are carrying out a visual processing task whereby they see the objects to be remembered. As argued earlier however, once visual processing has occurred, encoding is likely to occur in the verbal modality whereby individuals say the name of the objects to themselves as a means of aiding the memory process. They must selectively attend to each object in order for the encoding to occur.

Attentional switching should not be a particularly pertinent aspect of attentional functioning within the VR free recall task as the subject is not likely to switch from one aspect of the task to another. The demand for attentional switching is only likely to arise in a situation where the subjects have difficulty negotiating their way round an object or through a doorway. This situation would require the subject to shift their attention from the memory task to the motor task concerning manipulation of the joystick. It was apparent while carrying out the VR assessment that some individuals did have difficulty using the joystick to move through the virtual rooms. The ability of the subjects' to use the joystick efficiently varied greatly and is likely to have had great implications for the individuals' success in the VR memory tasks. Those who found it more difficult to negotiate their way through the virtual rooms (who got 'stuck' more often) would require a greater degree of attentional switching in order to complete the task than those who found it easier to use the joystick. This will be discussed more fully in section 4.6.1.

4.3.6.2 Cognitive components of VR recognition

The results here are particularly surprising in that verbal memory does not make any independent contribution to the variance in the VR recognition task. It was hypothesised that verbal memory would play an important role in the cognitive processing of this task as it is an explicit memory task requiring subjects to recognise the objects they have seen in the virtual environment. The emphasis here is on retrieval of information with subjects simply recognising the stimuli rather than having to access the information independently. Verbal memory only makes a contribution to the cognitive processing in the VR recogniton task in the context of *shared variance* however, that is, the verbal memory task shares some of the cognitive processing factors with visual memory, visual selective attention and speed and attentional switching.

8.4 % of the variance in the VR recogniton task is accounted for by visual selective attention and speed. This makes sense, as discussed in the previous section, in that the VR assessment requires the subjects to selectively attend to the visual stimuli in order for memory processing to occur. There is a greater component of visual selective attention in the VR recognition task than in the VR free recall task, probably by virtue of the fact that there is a greater emphasis in the recognition task to process visual information.

10.4% of the variance in the VR recognition task is accounted for by attentional switching. It is unclear why this should account for such a large proportion of the variance here as the VR recognition task does not logically require a great deal of attentional switching. As with visual selective attention and speed, it is surprising to find a discrepancy between the contribution of attentional switching in the two VR tasks.

4.4 THREE VR TASKS RATHER THAN TWO

The results concerning the actual cognitive components of the VR task are largely unexpected. The investigator however, would like to suggest that there are three VR tasks that should be considered rather than just two. This may therefore shed *some* light onto the current findings. The argument is that the VR free recall and VR recognition tasks are carried out after the subjects have negotiated their way around the virtual environment. The initial task that has not really been considered involves the motor component (moving around the virtual environment using the joystick) and the *registration* and *retention* components of memory processing. This task therefore is separate to the VR free recall and VR recognition tasks concerning the *retrieval* of information. To expand this further, the *initial* task logically requires divided attention (between the motor and memory tasks) while the VR free recall and recognition tasks do not. The initial task therefore has a dual task component while the VR free recall and recognitoin tasks do not. This is of great importance in terms of exactly what is being assessed in the VR free recall and recognition tasks. The main premise here is that the free recall and recognition tasks are not direct measures of success at the dual task, but are direct measures of very specific memory tasks. The motor component is likely to affect the subjects' success on the memory tasks but motor skills are obviously not required in the actual free recall and recognition tasks.

One of the main hypotheses of the study is that the VR tasks should logically require divided attentional processing. It is now being suggested that the *initial* VR task requires divided attention but that the free recall and recognition tasks *do not.* The individuals' abilities to divide their attention will necessarily affect the amount of information they can recall and the amount of stimuli they can recognise, but divided attention is not actually involved in the free recall and recognition tasks. The main question to ask now therefore, concerns the exact cognitive functions that would be expected to be involved in the VR free recall and recognition tasks. To ask this question in retrospect, with the actual results to hand, may seem invalid. It is argued however that the results are still not what would be expected, but that the investigator is now in a position to appreciate the theoretical demands of the tasks more fully, in view of having made the differentiation between the three tasks rather than just two.

4.5 COGNITIVE COMPONENTS OF THE VR TASKS - REVISITED

4.5.1 Cognitive components of VR free recall - revisited

It is suggested therefore that the VR free recall task should require two main factors in the cognitive processing, namely verbal memory and sustained attention. Both of these components of cognitive processing wrere hypothesised initially as being an important components of the VR free recall task. The results have indeed verified the involvement of verbal memory in this task. The subtests measuring sustained attention (elevator counting and telephone search while counting) however, do not correlate significantly with the VR free recall task at all. It can be concluded therefore that sustained attention is *not* involved in the cognitive processing within the free recall task. An alternative explanation however, is that the subtests (elevator counting and elevator search while counting) are not particularly sensitive measures of sustained attention. The 'telephone search while counting' task in particular, was initially designed by Robertson et al (1995) as a measure of *divided attention*.

Sustained attention is defined as the capacity to maintain attention over a period of time. In the VR assessment however, the subject is in control of his/her movement through the virtual rooms and there is therefore no penalty if he/she shifts attention onto something else. The tests of sustained attention in the TEA depend on attention processing over a period of time, with inherent penalties if the subject fails to sustain this, that is the subject will miss the stimuli being presented. In the elevator counting subtest, for example, if the subject fails to sustain attention, he/she will lose count of the tones presented on the audio tape. In the VR task, on the other hand, if the subject fails to sustain attention, he/she will not actually miss any of the stimuli, as he/she is in control of exposure to the stimuli. It can be understood therefore, that, although the subjects must attend to the VR task over a period of time, this does not invole sustained attention in the strictest sense, as lapses in attention can occur with no negative effects.

An alternative explanation for the apparent lack of sustained attention within the free recall task may be that elevator counting is based on auditory stimuli while telephone search while counting is based on auditory and visual stimuli. The emphasis on auditory stimuli may be a confounding variable here, in that the free recall task is based on visual stimuli largely with verbal encoding. On describing the attention system within the human brain (see section 1.4.3) it was made apparent that the sustained attention processing seems to be localised to the right fronto-parietal area of the brain (Pardo et al, 1991). Different modes of stimulus input may have a confounding effect on the involvement of sustained attention, depending on the localisation of each individual's brain injury. In order to verify this, it would be necessary to carry out further research using a test of sustained attention that involved visual/pictorial stimuli. It could then be determined whether or not the type of stimuli affects the attentional processing being carried out. This entire argument is based on the proposal that sustained attentional processing of visual information is somehow different to the sustained attentional processing of auditory information. The initial processing of these two types of stimuli would obviously be different while the sustained attentional processing at a higher level would still be the same, probably occuring in the right frontal area of the brain.

4.5.2 Cognitive components of VR recognition - revisited

Having made a distinction between three VR tasks rather than two, it is proposed that the VR recognition task should require sustained attention, verbal memory and/or *visual recognition memory*. As discussed in the previous section regarding VR free recall (section 4.5.1) the apparent unimportance of sustained attention may be due to the actual sustained attention subtests being used. In relation to the memory components involved in the VR task, it is apparent that the researcher has so far failed to consider the fundamental differences between the two aspects of retrieval, that is free recall and recognition. These memory tasks are different, to some extent, in terms of the cognitive processes required to complete them. In recognition tasks, the subject is presented with different stimuli and has to select the ones which have previously been encoded and retained, during the actual learning trial(s). The subject is therefore being asked to internally scan stored memories, to see if he/she has an internalised representation of the stimulus being presented. Free recall on the other hand, requires the individual to generate his/her own cues and *then* to choose from the various internal cues that have been generated. Free recall therefore, is the more difficult procedure of the two. Best (1989) refers to these two cognitive models as **generate and recognise** models.

The results concerning the VR recognition task may therefore be understood in terms of this procedure of scanning internalised representations of the stimuli.

As the results have shown that the VR recognition task does not rely on verbal memory processing, it may be proposed that this task actually involves recognition in the visual modality. It has been proposed until now, that encoding of the visual information in the virtual environment has been verbal. It may be however that for the recognition part of the VR assessment, the processing relies on scanning internal *visual* representations of the stimuli rather than internal *verbal* representations. This suggests however that processing occurs both visually and verbally but that VR free recall primarily concerns processing in the verbal modality while VR recognition possibly requires processing primarily in the visual modality. The individual in the VR recognition task is, after all, being asked about recognition of *pictures*. In order to address this further it would have been ideal if the design learning test had had a recognition trial equivalent to that in the list learning test. Alternatively, subtest 4 (picture recognition) from the RBMT could have been incorporated into the linear regression equation, as a direct measure of recognition memory for non-abstract visual stimuli.(See section 2.2.2).

4.6 METHODOLOGICAL FLAWS

4.6.1 Difficulties concerning the motor task

As described in section 4.3.6.1, it was apparent while carrying out the study that some subjects had far more difficulty completing the motor task, with the joystick, than other subjects. One confounding variable here is the degree of impairment in the individuals' motor skills. As mentioned in section 2.5, subjects were excluded from the study if they had motor control problems preventing easy use of the joystick. When recruiting subjects, it was necessary to go through the medical files in detail. Anybody whose medical file mentioned motor difficulties was automatically excluded from the study. Subjects who did take part in the study were asked on completion of the practice run in the virtual environment, if they were able to use the joystick comfortably. All subjects reported that they could manage to use the joystick without any difficulties. On carrying out the actual VR task with the objects presented in the virtual rooms however, it was apparent that some subjects found the motor task very difficult. Some got stuck at regular intervals and found it difficult to negotiate their way past

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The fact that some subjects found the motor task difficult will also act as a confounding variable in relation to the time taken to complete the VR task. The following hypothesis could be proposed in relation to the motor task;

If the subject finds the motor task easy, he/she will remember more of the objects presented in the virtual environment. This hypothesis presumes that if the subject finds use of the joystick easy, this will be relatively automatic, allowing more attention to be devoted to the encoding/memory task. The other side of this hypothesis is that **if the subject finds the motor task difficult, he/she will remember less of the objects presented in the virtual environment.** If the subject has difficulty using the joystick, more effortful processing will be required for this part of the assessment. He/she will therefore attend less to the encoding/memory task, with the result that fewer objects will be recalled.

Another two hypotheses can be proposed however, in relation to the time taken to complete the task, as follows:

2) The longer the subject takes to complete the task, the more information will be remembered. This hypothesis presumes that if the individual spends more time in the environment, he/she will encode more information and will therefore be able to recall and/or recognise more information.

3) The longer the subject takes to complete the task, the less information will be remembered. If the subject spends longer in the virtual environment, this may be due to difficulties with encoding. Subjects may explore the environment for longer, with a view to the objects. The demand for motor skills in the actual VR task is therefore greater than the demand for motor skills in the practice run. This is likely to have a confounding effect on the amount of information that subjects were subsequently able to recall, in both the free recall and recognition tasks. This is by virtue of the fact that if subjects are having to attend largely to the motor task, they will be unable to attend as fully to the memory task, that is the task of *encoding*. If the information is not encoded effectively, the subsequent retrieval will necessarily be poor whether in the free recall or recognition domains. Another component which is likely to affect the time taken is the subject's level of familiarity with the use of a joystick. This will be discussed in section 4.7.

The fact that some subjects found the motor task difficult will also act as a confounding variable in relation to the time taken to complete the VR task. Two contradictory hypotheses could be proposed in relation to the motor task, as follows;

1) If the subject find the motor task easy, he/she will remember more of the objects presented in the virtual environment. This hypothesis presumes that if the subject finds use of the joystick easy, this will be relatively automatic, allowing more attention to be devoted to the encoding/memory task.

2) If the subject finds the motor task difficult, he/she will remember less of the objects presented in the virtual environment. If the subject has difficulty using the joystick, more effortful processing will be required for this part of the assessment. He/she will therefore attend less to the encoding/memory task, with the result that fewer objects will be recalled.

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Ability to use the joystick and time taken to complete the task, are obviously inter-related. It is not possible to determine from the current data however, which of the hypotheses are likely to be correct.

4.6.2 Problems concerning the memory failures checklist

One important aspect of the current study is the fact that the profile scores on the RBMT did not correlate as highly with the memory failure checklist scores ($r = -0.4324$) as they did in the RBMT validation study carried out by Wilson et al (1985) ($r = -0.75$). As mentioned in section 2.4, the memory failure scores in this study are based on a maximum of two hours of observation concerning each subject. Some of these scores however are based on as little as one half - hour period of observation. (This was determined entirely by the number of checklists that were returned to the researcher by the carers/relatives.) The checklist scores used by Wilson et al (1985) were based on a mean of 35 hours of observation concerning each subject. It may therefore be the case, that the checklist scores in the current study do not give a particularly accurate measurement of memory failures experienced by subjects in day to day situations.

4.6.3 Prorated scores on the RBMT

As mentioned in the method section (2.2.2) five of the patients had mobility problems and were unable to walk or move round the room independently in their wheelchairs. They were therefore unable to complete the subtests of the RBMT whereby the subject is asked to remember a route round the room and to then retrace the route, both immediately and after a delay. This also affects the subtests concerning the immediate and delayed delivery of a message, that is the message is meant to be left in a certain location each time, while retracing the route. Prorated scores were therefore used as described in section 2.2.2. This is likely to have affected the results of the study to some extent but there is no way of knowing exactly what score *would* have been achieved if the subjects had been able to move independently round the room.

It may have been better to have excluded these patients from the study, rather than prorating their scores. Due to time constraints and difficulties in recruiting subjects however, this was not felt to be a viable option. A different way of dealing with this situation would have been to develop some sort of analogous assessment which did not depend on the mobility of the subjects. This was discussed in the early stages of the study whereby a model room could have been used with model figures being moved around the room in order to retrace the route. This would have eliminated mobility problems simply by placing the emphasis on the subjects' manual skills. All of the five subjects in question would have been able to do this manual task. It was decided however that this task was not similar enough to the RBMT subtests and would have introduced alternative confounding variables to those in the chosen solution, that is - prorating the scores.

4.6.4 Time span for completion of all testing

It had initially been intended that the assessment procedures carried out in this research study would be completed within one week for each individual. This was felt to be particularly important for inpatients who had recently suffered neurological damage, as more change was likely to occur in their cognitive abilities. That is, in the first few weeks/months after neurological insult, the recovery rate is generally faster than at one or two years post insult. It was felt therefore, that those who had suffered neurological insult relatively recently would be in the least constant state of cognitive functioning, that is they would be recovering and their cognitive abilities at eight weeks post insult (for example), could be significantly greater than their cognitive abilities at five or six weeks post insult (for example). This would therefore have a confounding effect on the assessment data. This issue was not felt to be as important for those who had experienced neurological damage one or two years previously, as these individuals would have reached a more constant level of cognitive functioning.

Despite the theoretical rationale for completing all testing within one week for each individual, this proved to be impossible in practice. The inpatients were often in different therapies, being attended to by nurses, feeling unwell or else sleeping, when approached by the researcher. Because of this, some of the subjects were tested over a period of time as long as three weeks. This must be borne in mind, although the extent to which it has influenced the results can not be determined.

4.6.5 Virtual objects presented in the virtual world

As can be seen from table 2.1 in section 2.1.3, the objects that were presented in the virtual environment are fairly typical of what you would expect to find in somebody's own home. This may have influenced the results in that individuals could easily have named various typical household items in the free recall trial without actually remembing them from the virtual environment. This would give them a higher score for the VR free recall task but the score would not necessarily be representative of the amount of information the individuals could genuinely recall. The current researcher certainly got the impression from some of the subjects that they were guessing about the household items rather than actually recalling them. This is quite understandable if a subject is having genuine difficulty in recalling what has been seen. It may be easier to guess, and to maintain morale to some extent, rather than to admit that he/she can not remember what was in the virtual environment.

4.6.6 Added distraction while completing the VR assessment

The first distraction factor to be addressed is extraneous conversation while subjects were moving round the virtual environment in the encoding part of the assessment. Some of the subjects completed the initial VR task without talking at all, thus helping to maximise their ability to attend to the objects presented within the rooms. Other subjects however, talked intermittently while moving around the virtual rooms. Such conversation would serve as a distractor and thus reduce the amount of attention the subjects could devote to the memory task. The researcher tried to minimise any conversation during the test, as much as possible, by asking the subjects to conentrate on remembering the objects. There is perhaps a greater risk of subjects talking during the VR assessment than during other forms of cognitive assessment as the researcher is sitting beside the subjects but is not actively involved in the assessment procedure at this stage. Some subjects may therefore feel more inclined to involve the researcher/clinician, by initiating conversation. This could have been minimised further if the researcher has sat further from the subject/outwith the subject's field of vision, during this part of the assessment procedure. It was felt necessary for the researcher to sit next to the subject however, in order to observe the computer screen and help the subject through the task. This, however introduces a second distraction factor; that of interuption from the researcher.

Some subjects did not manoeuvre round the virtual environment fully enough, with the result that not all of the virtual objects would be seen. On such occasions, the researcher would make suggestions to the subjects, such as; "remember to look all around you to make sure you see everything". The rationale here was obviously that, if the subject did not see every object in the virtual rooms, then he/she would be unable to process the information for retrieval later on, thus affecting the actual memory component of the assessment. By prompting some subjects in this way however, the researcher was possibly distracting them and interrupting their memory processing.

It was thought to be important to mention this latter distraction factor in relation to the VR assessment. As all clinicians are aware however, concerning the administration of neuropsychological tests, absolute standardisation of testing procedures is very difficult to achieve. It is not being suggested therefore that the VR assessment is any worse in this respect to standard assessments being used by clinicians/researchers at the moment.

4.7 RESPONSE OF THE SUBJECTS TO THE VR ASSESSMENT

As reported in section 3.6.4, several positive comments were made by subjects regardng the VR assessment. The most pertinent comment made by one man was that the VR assessment felt more realistic than trying to remember a list of words. This part of the study was done informally. In retrospect, it would have been preferable to have had a more structured approach to assessing individuals' opinions. This was not built into the experimental design however. Overall, subjects seened to think that the VR assessment was more interesting and enjoyable, and less threatening than standard assessments. On the negative side however, a few subjects mentioned that they found it difficult to use the joystick, or that they lacked experience in using computers. This is important in relation to their overall familiarity with the equipment being used. As mentioned in section 4.6.1, the extent to which the subjects have used a joystick before, is likely to affect their ability to negotiate their way around the virtual environment. This relates also, to the length of time subjects will take to complete the task. Some subjects for example, offered the information that they had frequently played computer games, using joysticks, in the past. These subjects certainly *appeared* to find it easier to manoeuvre around the virtual rooms and to move round the virtual objects. In a similar vain, the extent to which subjects had used computers in the past, is likely to influence thair performance on the VR tasks. Those who had never used a computer before, generally expressed more concern about what the VR assessment would involve. It could be argued therefore, that these subjects would have lower scores, by virtue of the fact that they were more apprehensive about the assessment and less confident about their abilities to carry out the tasks.

4.8 SUGGESTIONS FOR FUTURE RESEARCH

In relation to the validity of the VR assessment, it would be important to assess normal individuals, that is - those without neurological damage, and to compare the results with those from neurologically damaged individuals. This would be to determine whether or not the VR assessment is actually sensitive to neurological damage. The VR assessment should necessarily differentiate between neurologically damaged and non-neurologically damaged individuals, with significantly different scores between the groups.

Future research concerning this VR assessment should also address the issue of reliability. It would be necessary therefore to look at test - retest data on a group of normal individuals, to determine whether the assessment gives similar information on both occasions. To counteract any learning effects however, it would be necessary to change the objects presented within the virtual environment on the second administration of the test. In relation to this, it would also be worthwhile to develop parallel forms of the assessment so that individuals could be assessed at different times as a means of determining the degree of improvement in the individual's level of functioning.

Because of the apparent difficulties some subjects had using the joystick, future research should address the extent to which ability to use the joystick affects encoding and recall. One possibility here is that subjects may find it easier to negotiate their way through the environment in fully immersive VR. They would still be required to use use a joystick but, the increased realism would possibly minimise any difficulties.

In relation to the issue of ecological validity, the VR assessment definitely shows promise in enabling neuropsychologists to predict future levels of functioning. It would be worthwhile to address this issue in further detail in future research. The VR assessment should be administered to a much larger sample and correlated with objective ratings of memory failures over much greater periods of time than in the current study. The sample size in the validation study of the RBMT, concerning the objective ratings of memory failures was 80 and the average length of time for which individuals were obsereved, was 35 hours. A similar procedure could be carried out using the VR assessment rather than the RBMT. Results from the VR study could then be compared directly with results from the RBMT study to determine whether the correlation between the VR assessment and the checklist is greater than the correlation between the RBMT and the checklist.

In total, 51.5% of the variance in VR free recall is accounted for and 42.6% of the variance in VR recognition is accounted for. This leaves 48.5% and 57.4% of the variance (respectively) unexplained. Further research would be necessary therefore to determine exactly what other cognitive components are involved in the VR free recall and recognition tasks.

As mentioned in the previous section (4.7), the current study lacked a structured approach to assessing the opinions of the subjects who took part in the study. Future research could address this issue by giving questionaires to individuals after completion of the assesment.

Overall, virtual reality as a form of ecologically valid neuropsychological assessment shows great promise. A great deal of further research is required, however, before it could be used routinely in clinical settings. An important aspect of VR assessment worth further consideration, is that all aspects of cognitive functioning could feasibly be measured using the same technology, based on the same theoretical background. The current study has started to address the usefullness of VR in assessing memory and attention, but the same software could be adapted to assess language skills, executive functioning, perception and so on, in the visual, verbal and auditory modalities. This would eliminate any problems concerning the use of tests which may have some important qualities, but lack other neuropsychological qualities that are considered to be vital. The RBMT for example, meets the criteria for ecological validity but lacks the theoretical background to be of particular use in terms of functional - anatomical specialisation.

One final comment in favour of VR assessment procedure is that they can lead directly onto the rehabilitation of individuals with neurological damage. This relates back to the concept of reduced cerebral arousal/activation. By interacting with a virtual environment, the individual will necessarily increase their behavioural interaction and cerebral arousal/activation, thus aiding recovery. Any newly developed VR assessment procedures could therefore be expanded for use in neurological rehabilitation.

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Standard Script for the Virtual Reality Assessment

Instructions for the VR practice run.

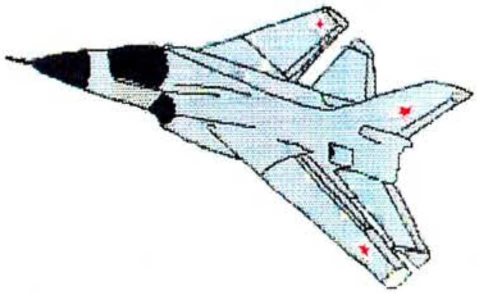
The first task is not part of the actual assessment, it is just a practice run so that you get used to using the joystick. You need to use the joystick to move around the four rooms that will be shown on the computer screen. If you push the joystick away from you, you will move forward in a straight line. If you pull the joystick back towards you you will move backwards in a straight line. If you push the joystick to the right, you will rotate around to the right and if you push the joystick to the left you will rotate around to the left. (Demonstration from researcher while explaining how to use the joystick.) Take your time to move through the rooms so that you get used to using the joystick. Please ask me to help if you find it difficult.

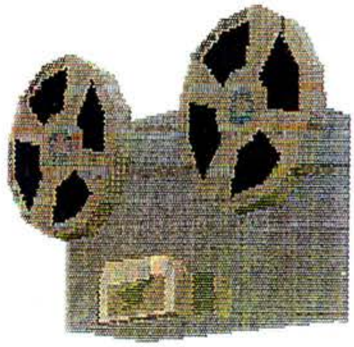
Instructions for the VR assessment.

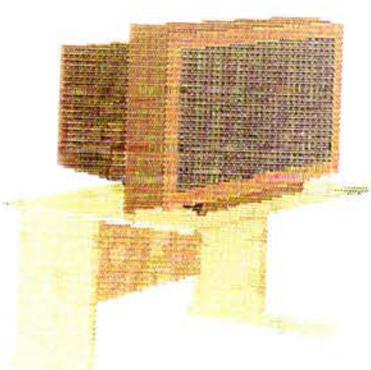
Now I'd like you to move through the rooms again, just as you did just now. This time, there are lots of objects placed around the rooms and I'd like you to try to remember as many of them as you can.Try to look all around you in each room, to make sure you see everything. Once you have been through all four rooms, I will ask you what you can remember.

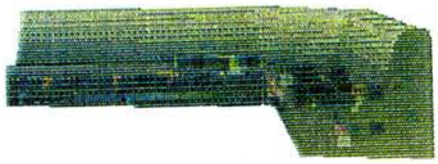
Instructions for the recognition task.

I am now going to show you some pictures of different objects. You will recognise some of them from the rooms. There are others that were not in the rooms, that you have not seen before, so you will not recognise them. Look carefully at each picture and tell me, for each one, if you recognise the object. If you are unsure, it is OK to guess.







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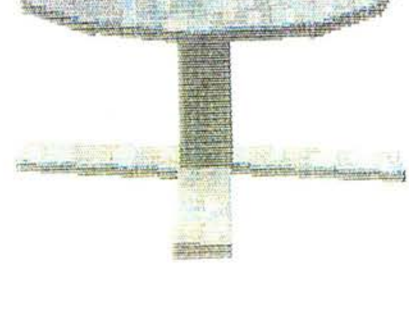
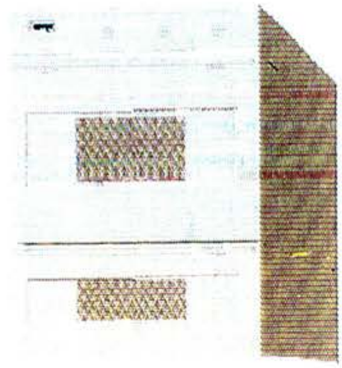
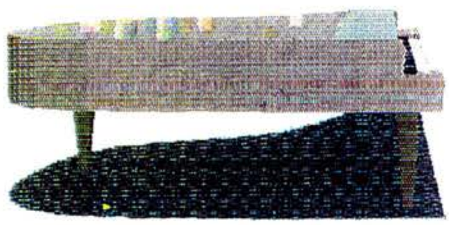
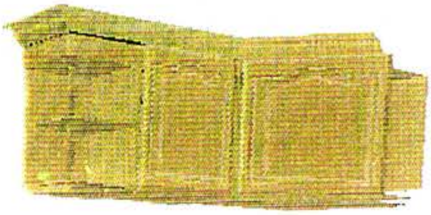
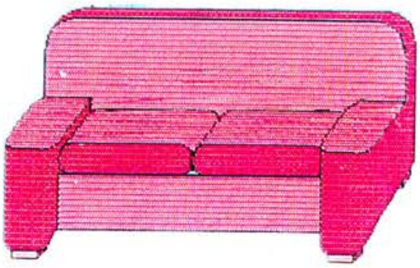


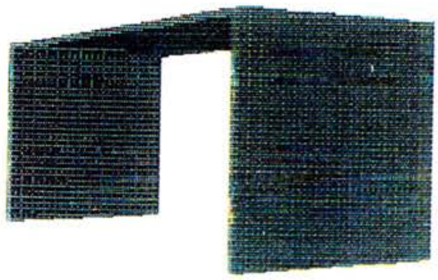


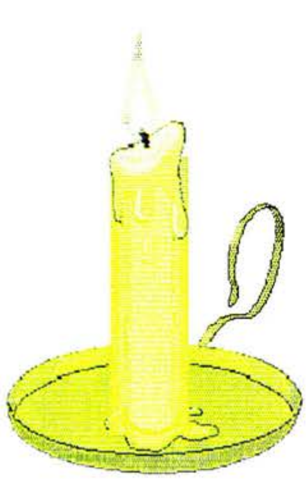

PUT ASHES IN
THEIR PLACE

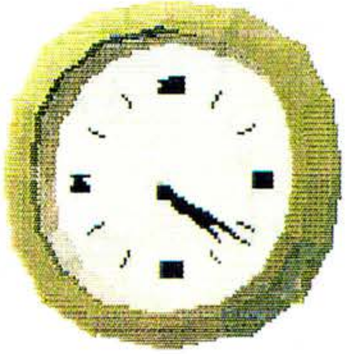


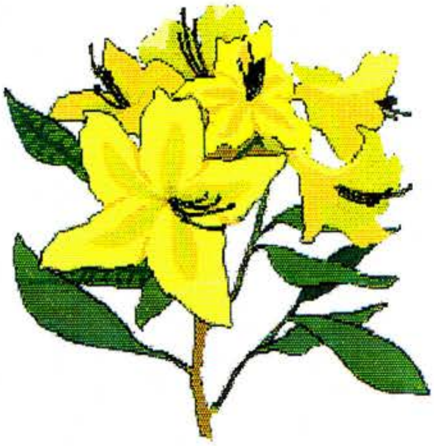


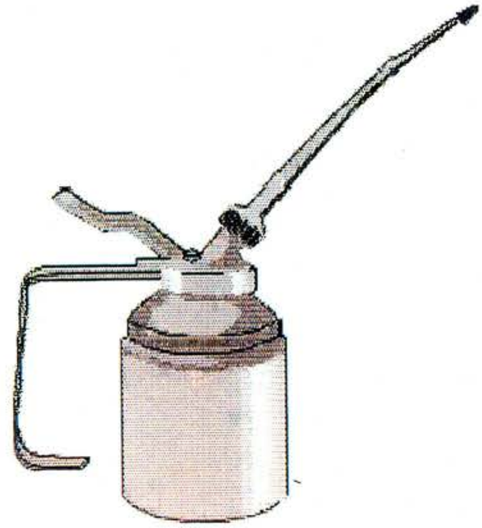


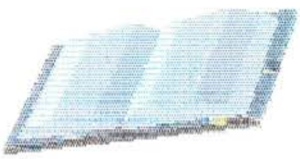


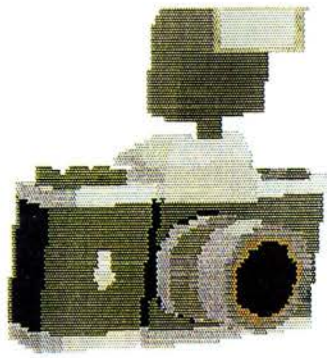


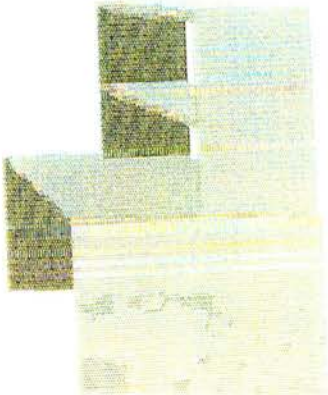


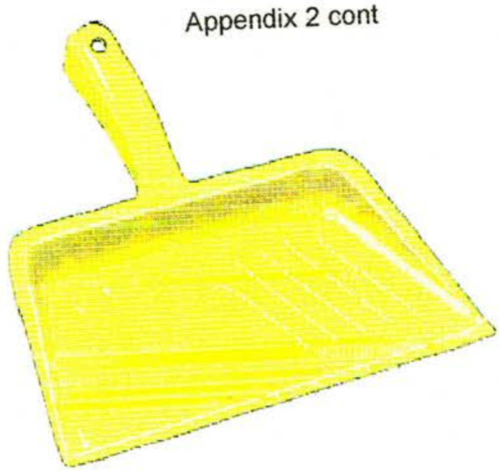


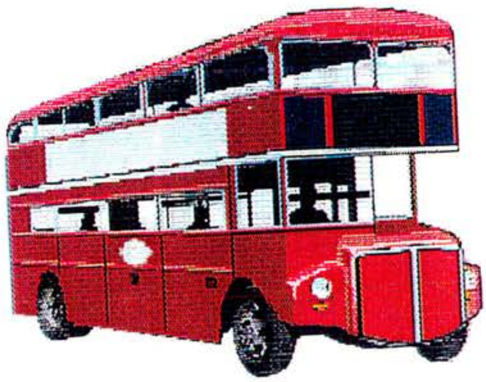


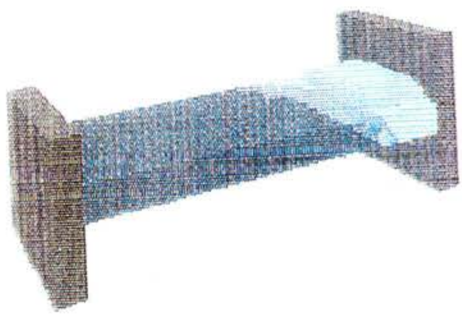


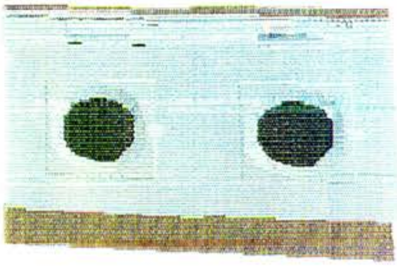


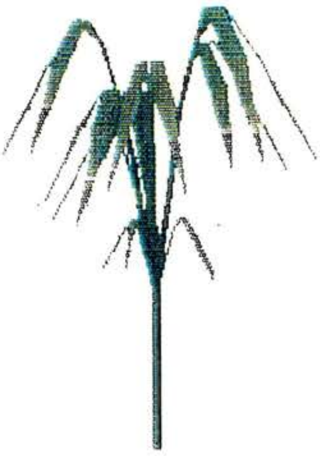


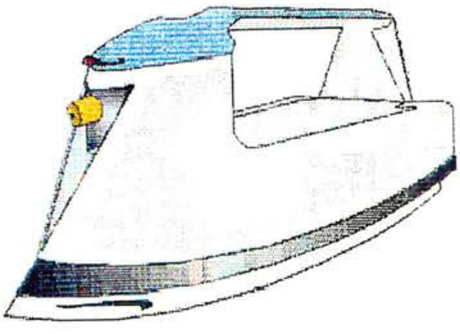


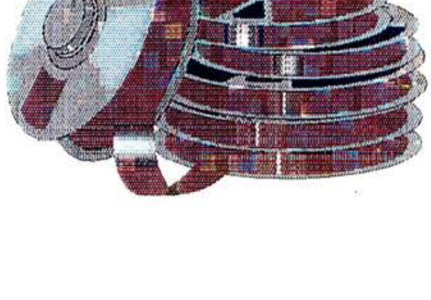












MEMORY FAILURES CHECKLIST

Patient ....

Checklist completed by................................ Date..	Please tick if any of the following memory failures occurred during the session.
A. FORGETTING THINGS: Did he/she.... 1)Forget **things** he/ she **was told** yesterday or a few days ago and have to be reminded of them?	
2) Forget **where** he/she had **put something** or lose things around the department?	
3) Forget where things are **normally kept** or look for things in the wrong places?	
4) Forget **when** something had happened, for instance whether it was yesterday or last week?	
5) Forget **to take things** with him/her or leave things behind and have to go back for them?	
6) Forget **to do things** he/she said he/she would do?	
7) Forget **important details** of what he/she had done the day before?	
8) Forget **details** of his/her daily **routine**?	
9) Forget a **change** in his/her daily **routine**?	
10) Forget the **names** of people he/she has met before?	

B. IN CONVERSATION: did he/she..... 1) **Ramble on** about unimportant or irrelevant events?	
2) Find words on the **'tip of the tongue'**, knowing the word but not quite able to find it?	
3) Get **details** of what someone has said **confused**?	
4) Tell a **story or a joke** he/she has told before?	
5) forget what he/she had already said, perhaps **repeating** what he/she had just said, or saying 'what was I talking about?'	
C: ACTIONS, Did you observe the patient........ 1) Having difficulty with **picking up a new skill**, eg. playing a game or learing to use a new gadget?	
2) **Checking up** on whether he/she has done things he/she intended to do?	
3) **Getting lost** on a journey or in a building where he/she has been before?	
4) Forgetting what he/she was originally doing **after becoming distracted** by something else?	

Any other comments or observations:

subject	age	list total	list errors	list 6	list errors 6	list distrac-tor	list recog-nition	list recog errors
1	19	38	8	10	1	4	14	8
2	47	10	2	2	0	1	7	5
3	27	14	12	1	3	2	7	0
4	26	26	0	4	0	4	9	7
5	37	51	0	10	0	6	8	1
6	49	45	0	11	0	4	15	15
7	56	52	0	11	0	5	15	0
8	22	21	8	3	1	2	7	3
9	46							
10	36	49	0	8	0	3	13	0
11	21	39	0	5	0	4	14	8
12	50	24	1	4	0	4	12	3
13	64	54	1	11	0	10	8	3
14	52	28	0	4	0	2	8	1
15	63	24	8	5	1	4	7	2
16	46	39	0	5	0	4	9	8
17	49	32	5	6	0	4	9	8
18	64	24	0	2	0	4	8	3
19	49	45	0	10	0	6	15	0
20	36	35	0	5	0	4	9	1
21	30	45	4	10	1	5	12	1
22	54	49	0	8	0	3	13	0
23	23	51	3	9	0	6	10	3
24	46	36	0	4	0	4	7	2
25	19	24	0	2	0	4	8	3

subject	design total	design error	design 6	design error 6	design distract-or	Trails A	Trails B
1							
2	16	8	2	5	1		
3	16	6	6	2	5	135	235
4	24	10	4	3	5	106	203
5	31	22	5	6	6	38	78
6	40	1	7	0	7	151	380
7	26	5	5	0	4	19	37
8	13	1	0	0	0	36	109
9	18	20	3	4	2		
10	35	1	9	0	5		
11	27	9	6	3	1	55	143
12	16	20	3	3	3	65	132
13	11	7	6	3	1	29	49
14	24	15	5	3	3	64	159
15	8	22	1	5	3	51	103
16	27	9	6	3	1	55	143
17	19	16	5	6	3	26	63
18	11	24	3	4	2	31	115
19	28	9	9	0	1	55	133
20	28	6	7	0	3	51	157
21	31	12	9	0	5	20	46
22	35	1	9	0	5		
23	40	3	9	0	0	36	98
24	24	15	3	8	6	30	58
25	11	24	3	4	2	31	115

subject	Map 1	Map 2	elevator counting	elevator count distraction	visual elevator accuracy	visual elevator time	telephone search	telephone search count
1			7	4	4	4.4		
2	11	19	4				4.9	18.1
3	19	35	7	8	8	8.33	5.6	6.85
4	10	19	1	1	2	9.8	8.7	
5								
6			7	8	8	3.88	9.9	7.9
7	47	75	7	10	9	2.53	2.15	0.94
8								
9	15	27	4	5			4.45	
10			7	2	10	3.85		
11	26	47	7	9	7	6.5	3.25	3.3
12	4	12	6	10	8	5.7	9.85	6.7
13	40	67	6	10	8	3.33	2.8	1.8
14	25	42	6	6	7	6.2	4.15	5.3
15	19	31	7	0	9	6.9	4.9	2.0
16	26	47	7	9	7	6.35	3.25	3.3
17	37	73	7	7	9	4.42	1.95	1.45
18	23	45			7	6.6		
19	26	46	4	4	8	3.45	4.06	6.8
20	22	34	7	3	8	5.6	5.3	3.46
21	47	77	7	10	10	2.65	1.98	0.25
22			7	2	10	3.04		
23	33	69	7	9	5	3.08	2.45	1.95
24	33	59	7	10	8	4.93	2.9	1.35
25	23	45			7	6.95		

subject	VR free recall	VR free errors	VR recog-nition	VR recog-nition errors	VR path length	VR time	memory check-list	RBMT
1	10	0	13	0	55075	191005	1	20
2	13	2	24	1	56835	464108	1	18
3	8	0	18	0	35206	248809		16
4	8	1	7	4	51651	230901	3	5
5	12	2	14	1			0.66	22
6	13	1	20	0	32413	295008	2.5	18
7	16	0	18	1	32718	241598	1	23
8	9	1	16	2	21233	230090	5	8
9			24	2	54148	208707		12
10	14	0	21	1	37790	162700	1.5	15
11					36368	162110		22
12	5	0	7	0	40838	263201	3.66	18
13	19	0	21	0	37062	762302	1.66	23
14	16	2	24	3	47170	302795	2.66	14
15	8	1	16	1	38566	220106	4.5	19
16								22
17	7	11	17	5	41996	283596	3.33	17
18	22	0	16	4	37940	286109	3.5	19
19	19	1	23	1	44596	319918	1.66	15
20	14	0	18	1	32551	169292	1.5	17
21	20	1	23	0	41322	318699		22
22	14	0	21	1	31776	229898		15
23	18	1	21	1	51874	250100	0	24
24	9	1	15	7	33157	174401		17
25	12	0	16	4	35080	219803	1.66	15

subject	age	list total	list errors	list 6	list errors 6	list distrac-tor	list recog-nition	list recog errors
26	31	46	6	6	3	7	11	2
27	43	42	2	8	1	4	14	0
28	42	35	2	4	0	3	9	3
29	59	33	0	4	0	3	12	0
30	39	41	4	6	0	7	10	2
31	41	35	2	6	0	4	12	0
32	44	33	6	3	0	4	9	5
33	35	29	1	6	0	3	9	2
34	64	42	3	7	0	4	13	0
35	52	48	4	6	2	6	12	2
36	49	35	1	6	0	5	11	2
37	59	26	1	4	0	4	10	2
38	56	52	0	9	0	4	13	1
39	63	35	0	5	0	5	10	0
40	32	44	5	7	0	6	14	1
41	45	26	1	4	0	2	8	4
42	53	36	0	5	0	4	10	4
43	61	32	2	6	0	4	8	2

subject	design total	design error	design 6	design error 6	design distract-or	Trails A	Trails B
26	21	23	2	4	4	27	83
27	28	7	7	2	4	35	71
28	21	14	3	2	2	30	65
29	20	18	4	4	2	35	78
30	23	12	3	2	4	41	99
31	24	16	7	0	4	41	99
32	14	16	3	6	2	87	158
33	22	21	5	3	2	46	79
34	24	11	7	0	4	37	68
35	31	18	5	4	4	25	52
36	14	21	5	7	3	39	71
37	21	15	4	4	3	58	119
38	35	8	6	1	3	23	49
39	31	14	6	2	3	47	127
40	20	20	5	3	4	31	58
41	17	12	1	4	1	51	108
42	29	15	3	5	3	32	49
43	20	21	4	4	3	22	53

subject	Map 1	Map 2	elevator count-ing	elevator count distract-ion	visual elevator accur-acy	visual elevator time	tele-phone search	tele-phone search count
26	27	54	7	4	9	3.8	3.6	4.9
27	34	49	7	4	9	2.9	4.9	2.45
28	38	59	7	7	8	7.2	3.65	2.04
29	29	49	6	6	7	5.8	3.2	4.85
30	20	36	7	6	8	6.4	5.6	2.65
31	19	34	7	9	9	3	5.8	2.8
32	13	23	5	4	6	7.95	7.2	8.3
33	28	39	6	6	8	5.65	5.5	4.02
34	31	45	7	5	8	5.65	3.55	2.85
35	29	54	6	5	9	3.64	3.05	4.3
36	19	43	6	6	8	6.05	3.2	4.8
37	15	27	6	8	8	6.3	8.45	5.65
38	38	55	7	8	10	2.55	3.55	2.96
39	26	39	7	7	9	3.25	5.6	2.32
40	28	50	6	8	10	2.85	2.25	2.55
41	17	28	5	5	4	6.95	6.2	3.8
42	35	56	7	8	8	4.55	2.55	2.82
43	31	65	7	7	9	3.05	1.85	1.98

subject	VR free recall	VR free errors	VR recog-nition	VR recog-nition errors	VR path length	VR time	memory check-list	RBMT
26	18	5	22	8	32284	155202	2.5	22
27	17	1	22	1	34189	290500	1.33	18
28	12	1	13	0	49102	229692	2.66	15
29	17	2	22	0	36492	155899	2	15
30	15	1	19	0	52404	210280	1	16
31	14	2	20	0	37908	319569	2.5	21
32	10	0	16	3	34142	195269	2.66	17
33	13	0	17	2	34142	195269	1.33	12
34	17	0	22	4	42404	158402	0.66	18
35	18	3	23	6	43690	172906	0.0	22
36	13	0	17	4	47440	340802	2.33	16
37	9	0	12	2	52906	219289	3.5	16
38	17	0	24	0	41107	177804	1.5	23
39	14	0	20	0	35208	185989	1.33	19
40	18	0	22	0	39107	177803	2.33	18
41	8	0	14	3	36338	311918	1	13
42	13	2	16	3	48777	180746		16
43	9	1	14	6	41348	214843	1.33	17